

School of Engineering and Energy

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Engineering Thesis

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**A PHOTOVOLTAIC TRAINING FACILITY ON THE MURDOCH
UNIVERSITY ENGINEERING & ENERGY BUILDING'S NORTH EAST
ROOF**

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Except where I have indicated, the work I am submitting in this report is my own and has not been submitted for assessment in another course.

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ENG460 Engineering Thesis

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I am satisfied with the progress of this thesis project and that the attached report is an accurate reflection of the work undertaken.

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Abstract

Murdoch University's School of Engineering and Energy is expanding its facilities to include a, total of 8.2kWp, Photovoltaic (PV) Training Facility. This facility has incorporated four types of PV modules and equipment, including mono-crystalline, poly-crystalline, amorphous, and copper indium gallium selenide thin film modules; isolated, high frequency isolated, and transformerless inverters; AC and DC test points; emergency stop button system and other safety devices; a battery bank, and power meters.

These facilities will provide a versatile educational resource for students to analyse the behaviours of a wide variety of PV technologies.

This project has examined the process of writing an Invitation To Offer (ITO), reviewing the ITO with recommendations for future engineering projects, and detailing changes in the design of the systems as the project developed.

A recommendation has been detailed in this project for the inclusion of a PV monitoring station, which should monitor environmental parameters at the PV site.

A manual and simulated performance ratio (PR) of all PV systems has been examined in this project. The manual estimate calculated a PR of 0.739 over the period of a year. For the simulated PR, PVSYST software was programmed and calculated a yearly PR of 0.745. This modelling indicates that the system performance would be comparable to similar systems in Perth.

Acknowledgements

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Chapter One - Introduction

1 Introduction

Murdoch University's School of Engineering and Energy offers education in renewable energy both through its Energy Studies and Engineering programs. The School is expanding its facilities to include the PV Training Facility, which will provide a versatile educational resource for students to analyse the behaviours of a wide variety of PV technologies.

The PV Training Facility will also contribute towards the University's pledge to invest in renewable energy by purchasing *Green power*, which currently supplies 16% of its electricity requirements [2].

1.1 Background

The PV installation was to contribute towards the teaching resources for the School of Engineering and Energy. The arrays were to be located on the north east side of the Engineering and Energy (E&E) Building's roof. Funds were allocated for the fabrication of a frame, walkway, and the PV systems. A walkway allows students and staff access to the rear of the arrays, which would allow them to inspect and maintain the array over time and attach or move test equipment.

The intention of the School was that the project funds would cover the PV systems, which included the frame, walkway, and all test equipment. The Office of Commercial Services (OCS) advised that the project funds were strictly for the tender responses to the Invitation to Offer(s) (ITO) issued. Any additional funds left from the tender responses would be put aside for unforeseeable changes from the initial design. This meant that the school would need to provide additional funding for the monitoring equipment, including weather data and system temperatures. For this reason this report has recommended the components of the monitoring equipment needed for the installation, which ideally would have been purchased and installed during this project.

The 'Invitation To Offer' was drafted and included the following components:

- A mono-crystalline type array.
- A poly-crystalline type array.
- Two types of thin film arrays.
- Different types of single phase inverter topologies.

- A battery bank 100Ah (C10).
- Patch panels – for measuring AC and DC currents and voltages.
- Four energy meters – one for each grid connection.
- The integration of the arrays into the existing lightning protection system.

The completion for this project was scheduled for the 4th December 2011.

The ITO was sent out to prospective companies with a tender submission deadline of 3rd September, 2011. The successful company was advised by the 16th September, 2011.

The frame and walkway for the arrays needed to be fabricated and installed before any work could start on the PV systems. Due to the structure of the building, reinforced on the north eastern roof area, this was the only suitable location for the array frame. This frame was installed in compliance with the appropriate building regulations and would be able to withstand the wind forces attributed to the installation's surface area. This work was completed during December, 2011.

1.2 Scope of the Project

The scope of this project included reviewing the designs of the PV arrays, which should be designed in compliance with all relevant authorities and the University's policies and procedures. The project also involved:

1. Reviewing the designs and overseeing the installation of the arrays.
2. Refining the system requirements and design in terms of monitoring and data logging.
3. Design and setup of a dedicated frequently recording (1 s basis) solar radiation and environmental parameter for system performance evaluation.
4. Assisting university staff with the specification of the system and the preparation of tender documents.
5. Assisting and liaising with contractors and university staff during the installation phase.
6. Documentation of the installation and project progress.
7. Analysis and documentation of the inclusion of the PV array structure in the existing lightning protection system and any lightning protection measures included in the design.
8. Simulation and performance estimation of the system.
9. Initial performance evaluation of the system once installation is complete.

Due to the installation of the system taking longer than expected, point 8 could not be completed, and as detailed in section 1.1 (point 2) of the thesis could not be completed in full. Point 6 was completed by the building's engineer as the building was still under warranty. However, the scope of the thesis has now included a review of the ITO as it lacked sufficient specific detail as to how the installation should have been performed, and what was to be provided by the University.

Chapter Two – Invitation To Offer

2 Invitation To Offer (ITO)

2.1 Companies to Receive the ITO

There are many companies in Australia that are accredited under the Clean Energy Council (CEC) to install PV arrays. However, Murdoch University only wanted to send out a limited number of invitations to three companies. For this reason the selection was limited to the Perth metropolitan area as this would make for easier communications and site visits with the prospective companies. The specifications of the original ITO can be found in Appendix A.

The justification applied to reducing the number down to the final three was that they gave the most confidence they could supply:

- The variety of products required for each array.
- The expertise to design the arrays.
- The resources to complete the arrays before December 2011.
- The professionalism to complete the contracts to a level of quality required by the university.
- The ability to respond for an initial interview when a detailed message was left for them.

For these reasons only three companies made it to a shortlist, which received the ITO. The ITOs were sent to these companies through the University's Commercial Services. The companies were given two weeks to respond to the ITO, which allowed an adequate amount of time to ask questions to Murdoch University.

2.2 Fielding Questions

Questions relating to the scope of the project were received by one company. These included:

- Expanding the scope of the project to install additional systems on the other roof surfaces for Solyndra modules (Figure 1). Solyndra modules were a product from the USA that harnessed irradiance through 360°, including from reflected surfaces
- Mounting system and style of the frame.

- Reducing the size of the frame to allow for Solyndra modules to be mounted directly onto the roof.
- Style, function and configuration of the patch panels.
- Using alternative types of modules instead of the SunPower E19 modules.



Figure 1: Solyndra Cylindrical Module [1].

Ultimately this tender was not successful due to the difficulties of incorporating Solyndra modules.

2.3 Tender Decision

The tender awarded for this project was successful for the following reasons:

- The inclusion of SunPower E19 modules.
- The ability to provide PV modules that would fit onto and within the PV frame area. These module types included mono-crystalline, poly-crystalline, amorphous, and another thin film (copper indium gallium selenide, CIGS) with line and high frequency transformers.
- The ability to provide a variety of inverter topologies, including: galvanically isolated, and transformer-less ones.
- Did not have any question or reservations adhering to the original ITO (this will be discussed in section 7.3).

2.4 Component Approvals

2.4.1 Module Approval

The modules installed by the winning tender were checked for listing on the ‘Currently approved modules’ list by the CEC [3]. This list verifies that all modules are compliant with AS 5033, IEC 61730, and IEC 61215 or IEC 61646, which was stipulated as a requirement of the ITO [4-7].

2.4.2 Inverter Approval

All the inverters installed by the winning tender were checked and listed on the ‘Western Power Approved Inverters’ list, [8] as a minimum requirement for grid tied inverters. Inverters listed have been verified that they are compliant with AS 4777.2, AS 4777.3, and AS3100 or equivalent, which was stipulated as a requirement of the ITO.

2.4.3 Compatible Modules and Inverters

The ITO requested a variety of different inverters and modules for educational purposes. However, not all modules are compatible with all inverters. The PV module manufacturers will generally stipulate the topology of the inverters their product would be compatible with, and where the manufacturer had not stipulated a configuration, a general rule would have applied that grounding should be used for thin-film modules.

The reason for following the recommended topologies for inverters by solar module manufacturers is the inherent risk with using transformerless inverters (floating array), which could cause an capacitive oscillating leakage current if not earthed the module frames. This could prove hazardous to anyone that touches the frame and could result in electrocution. Additionally, it has been found that ungrounded thin-film modules would accumulate corrosion of the transparent conductive oxide (film) in higher voltage installations. High levels of corrosion have been prevalent in ungrounded systems [9]. For this reason the following inverter and module configurations for the PV arrays were recommended Sun Brilliance.

Sunpower E19 mono-crystalline modules with a SMA SB2500HF inverter

The manufacturer states that the E19 (19.6% efficiency) 320W modules are compatible with transformerless inverters [10]. The Murdoch installation would be using E19 238W modules with 19.1% efficiency, which indicates a different structure to the 320W modules [11]. The SB2500HF inverter has a high frequency transformer, however the discrepancy between E19 modules would not affect the performance of this system [12].

HHV Solar poly-crystalline modules with a SamilPower Solar River 2300TL inverter

Insufficient information was provided on the manufacturer's recommendations for the HHV Solar modules despite requesting information from the contractor and HHV Solar. A general rule has been applied here that the modules are compatible with the transformerless and ungrounded Solar River inverter until more information is made available.

Q.Cells Q.Smart modules with SMA SB1100 and SB1700 inverters

The Q.Cells are CIGS modules that generally have lower corrosion in grounded systems due to their substrate structure [9]. This is reflected in the manufacturer's recommendation that the modules are to be grounded [13]. The SB1100 and SB1700 are

both inverters that came with grounding kits, which comply with the manufacturer's recommendation [14].

AmpleSun ASF100 modules with a Fronius IG20 inverter

The AmpleSun modules are composed of amorphous silicon, which must be grounded as per the manufacturer's guidelines [15]. The Fronius IG20 is an ungrounded inverter and can detect if the resistance between positive or negative and ground falls below 500 k Ω . The inverter would isolate in that situation [16]. This issue has been raised with the contractor and supervisor as it would affect the module warranty.

2.5 Companies Involved in the Project

The companies and their roles in the final fabrication and installation of the E&E Building's PV arrays were:

- **MACHIN** – The architect of the frame, walkway, and project manager for 4 weeks.
- **Cooper & Oxley** – The original builder of the E&E Building who fabricated and installed the frame and walkway.
- **Sun Brilliance** – The Company awarded the contract for supplying and installing the equipment needed for the PV arrays. Sun Brilliance supplied the main equipment for the installation; modules and inverters.
- **TPE Services** – Subcontracted by Sun Brilliance for installing and designing the PV module configuration with inverters, batteries, ducting, and cabling. TPE Services also designed and installed the Emergency Stop Button (ESB) system.

Chapter Three – System Design

3 Feasibility, Development, and Changes of the System Design

3.1 Weight Estimation

The E&E Building was designed with less consideration for future developments of PV systems on the roof. This building's support structure was only sufficient on the north side of the roof to support a modest array. Throughout this project consideration was given to estimated weight supported by the building, and as a result the maximum permissible weight that can be allowed on the structure after completion is 250 kg (maximum of 2 people). This weight was derived by the structural engineers after taking into consideration:

- The weight of the frame and walkway.
- The weight of the array, including modules, cables, cable trays, and junction boxes.

A calculation of the module weights provided to the structural engineer was made with an additional 25% allowance for the electrical cables, junction boxes, etc. The estimated weight was 1181.4 kg (Appendix B).

3.2 Wind Loading

The PV arrays mounted onto their frame would act similar to a sail in strong wind conditions. The structural support frame for these arrays needed to be able to support the wind loads as per AS1170.2 [17]. This is a requirement of the CEC System Installation Guidelines for Accredited Installers and Supervisors.

The roof deck plan detailed the wind loading on the framework [18]. This did not make specific mention to AS1170 for certification, but was detailed in an email from the structural engineer as complying with AS1170.2.

3.3 Thin Film Modules

The proposed Solar Frontier copper indium selenide modules outlined in the original tender submission were changed due to lack of remaining stock. The replacements proposed were Q.Cells Q.Smart 95 (CIGS). However, the final modules installed were Q.Smart 90 (CIGS). These modules were on the CEC's Approved PV Module list and could be used in conjunction with the SMA SB1100 and SMA SB1700 inverters [3].

3.4 Mounting Rail for the Modules

The cylindrical mounting rail for the modules was replaced with a roof mounting system from Antai New Energy [19]. The mounting system was replaced as the proposed U-shape plastic clamps were no longer available on the market (Figure 4).

3.5 Extra Low Voltage (ELV) Isolation

The module connectors will be used as the ELV disconnect for maintenance and segregation.

3.6 Battery Bank

The ITO directed the installation of a sealed battery bank to supply 100Ah (C_{10}), which must also comply with Australian Standards [2, 20-23].

The battery bank installation was understated in the ITO. The direction was to install a battery bank on the roof level located outside and just west of the double doors that lead out onto the roof (Appendix C), and the battery bank was to be built to Australian Standards [2]. However, as the ITO did not state directly that a battery enclosure was to be provided as a separate point then this was argued as an additional cost by the contractors.

3.6.1 Enclosure

Various types of enclosures were sourced as a solution to this issue, which included standard prefabricated enclosures, specifically designed enclosures by switchboard manufacturers, solar component retailer (made specifically), and currently unused university battery enclosures (Appendix D) [24-26]. However, the most appropriate solution was a standard garden shed that was modified to house the batteries in accordance with AS 2676.2, AS 3011.2, and AS 4086 (Figure 2). All the materials were less than a third of the price of the next most affordable solution. The University decided to cover the cost of the materials and requested the assistance of the engineering Technical Officer to assemble the enclosure. For more illustrations see Appendix E.

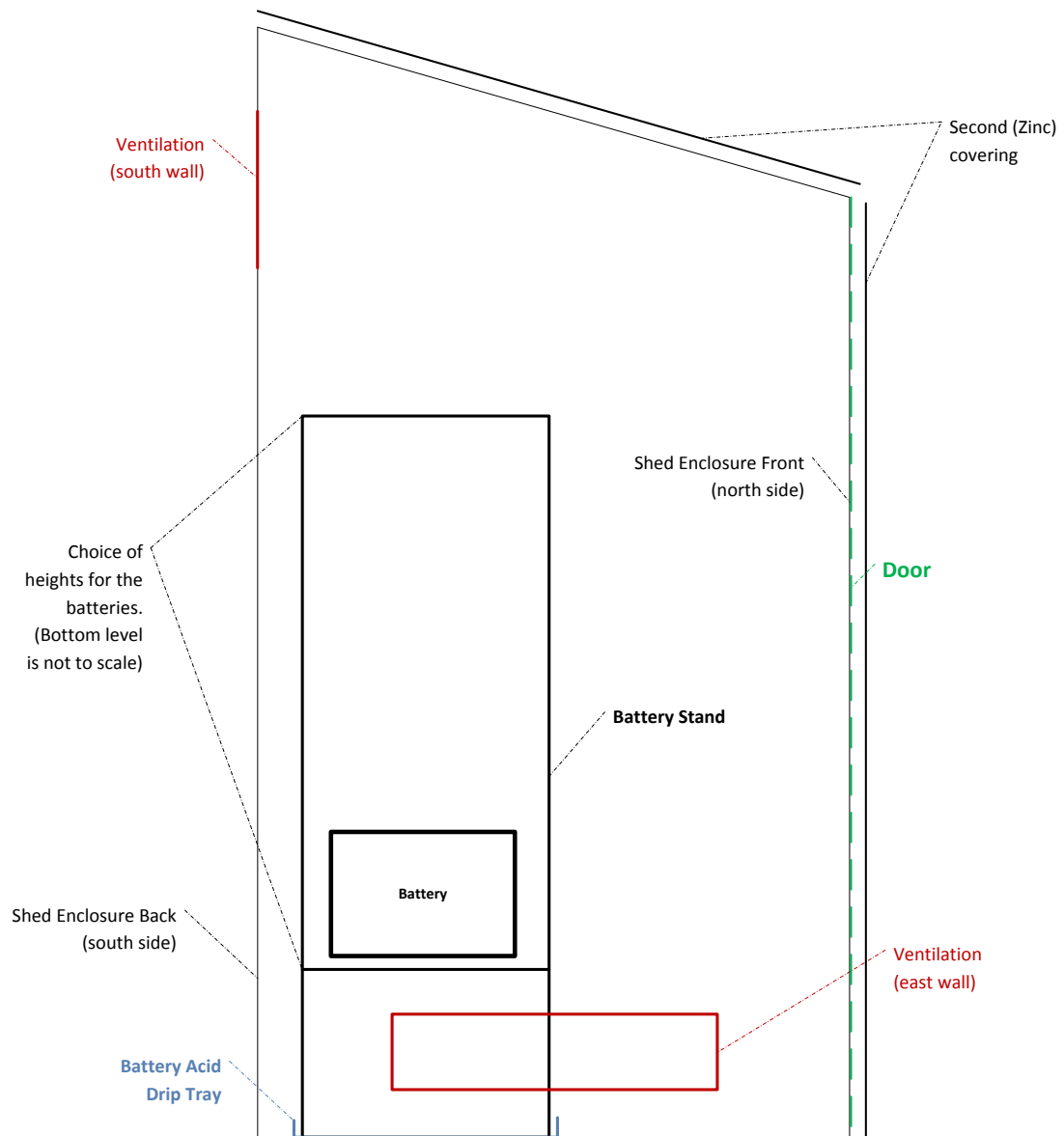


Figure 2: Sketch of the battery enclosure viewed from the east side.

3.6.2 Battery Stand

In addition to modifying a shed-style enclosure a battery stand was needed to reduce the shed's footprint so that it would fit into the space allocated. The School of Engineering & Energy was fortunate to acquire a variety of equipment used at Research Institute of Sustainable Energy (RISE) after it closed. This included two battery stands, one of which could be modified to fit into a shed and the space allocated on the roof for this equipment.

3.6.3 Battery Drip Tray

In case of a battery leakage from any one of the batteries a drip tray was installed at the base of the stand. This would prevent serious leaks from coming into contact with the shed enclosure, or from spilling out into the walking area around the shed enclosure. A

product called Makrolon was used for the tray as this is non-reactive and slightly absorbent with the battery's sulphuric acid [27]. This product was also chosen as it could be fashioned into the required shape for the tray and is expected to outlast the battery system. The corners of the tray were filled with silicon as this too is non-reactive with sulphuric acid.

3.6.4 Battery System Capacity

From the summary of the 2011 semester 1 ENG421 student project reports indicated a battery bank size of two to four strings of batteries depending on the battery make and model [28, 29]. Despite numerous requests for information, the battery make and model were not provided by the contractors prior to sizing of the enclosure. Therefore, it was prudent to size the enclosure to adequately fit the greatest number of battery envisaged for this system; this was four strings of four batteries.

3.6.5 Realisation of the Battery System

On reflection the size of the enclosure was 4 times greater than the actual system installed as the batteries had greater (Ah) capacity than what was anticipated. The system that estimated 4 strings of batteries were oversized for the requested specification, which could be attributed to a 25% depth of discharge (DOD) allowance on a 100Ah (C_{10}) system. A DOD was not stipulated in the ITO and therefore the installed battery bank has been sized appropriately. The enclosure and SBU5000 allows some capacity to expand the battery systems if required. However, the battery cable may need to be resized if this is considered. The final system should consist of 1 string of 4 batteries in series.

3.6.6 Ventilation of the Battery Enclosure

The calculation for the ventilation for the enclosure was outlined in AS 2676.2. It was a design decision to have natural ventilation as the enclosure is large enough inside for a temperature gradient to push the air out. The ventilation for the battery system has been designed for a much larger system as detailed in 3.6.4, which means that the four batteries should have sufficient ventilation. The area required for 16 batteries is 240 cm^2 . The ventilation area required for four batteries is 60 cm^2 . Installed ventilation would be 783 cm^2 ; for calculations see Appendix F. The ventilation should be installed with aluminium fly screen to prevent vermin from entering [23].

3.7 Energy Meters

There were many developments of the switchboard location and function from the proposed design. Prior to the ITO being written, the switchboard was to be incorporated into the E&E Building's electrical switchboard cupboard located on level 3. The proposed location was moved outside the cupboard and adjacent to the lift well in its own enclosure (Appendix C). Questions were raised as to whether the enclosure would prevent smoke escaping into the corridor in the event of a fire; the enclosure was to have smoke seals. In consultation with an external electrical engineer, advice was received that the switchboard, inverters, and cables were to be placed inside an additional smoke cupboard; the switchboard was to be moved onto the wall adjacent to the inverters and would be contained inside that additional smoke cupboard. On further scrutiny of the Building Codes of Australia (BCA) clarification was sought on whether the Code applied to the inverters [30]. Advice was received that the Code did not apply to the inverters; however, the switchboard was mentioned directly as requiring a non-combustible smoke-proof enclosure. This reduced the size of the smoke cupboard and allowed students greater access the inverters and equipment. However, the enclosure would be at a significant cost.

In consultation with TPE Services they could provide two sets of circuit breakers and used discrimination so that one set would trip before the second set. The set closest to the inverters would trip first; these could be reset by staff if the system was tripped under test conditions. The next set of circuit breakers would be located inside the electrical switchboard cupboard on level 3; these would need to be reset by a qualified university staff member or by an inducted electrical contractor to the university. This was a preferred option as this reduced the need for an additional switchboard and therefore smoke cupboard. However, this solution would move the power meters for each of the four grid feeds into the patch panels (test points), which under review of the BCA meant they would need to be enclosed in a non-combustible smoke cupboard.

As the most cost effective solution to this issue it was recommended that the power meters should be moved inside the electrical switchboard cupboard. The power meters must have separate readout displays and should be placed on the wall adjacent to the inverters' grid-feeding, including the automatic switch box.

3.8 Emergency Stop Buttons

Three ESBs have been installed as an additional feature to the original systems. This was primarily for the protection of staff and students conducting experiments from the

system patch panels. This ESB system could be used prior to locking the isolators, therefore responding faster in emergency situations. As a precaution all the isolators will need to be switched and locked in the off position in a continuing emergency (e.g. fire or damage to the system).

In design there were two further benefits in this system:

- The ESB will disconnect the DC array cables at a point closest to the modules. This would reduce the risk of fires starting at the inverters and burning their way out of the building to the arrays.
- The ESBs once activated can be reset by rotating out the button activated.
 - Advantage – This reduces the need to gain access to the switchboard cupboard to reset the circuit breakers in the case of accidental pressing of the ESB.
 - Disadvantage – Any person could rotate and re-activate all the systems in an unsafe situation, which reinforces the need to lock the isolators in the off position.

Outside the scope of this project and what was requested of the contractor installing the ESB, would be an interlock of the ESB system to the fire alarm system. It would be good practice if this operated automatically where access to the ESB was limited by smoke or fire.

3.9 Cable Fixtures beneath the Modules

The cables from the modules supported to the back of the frame are generally fixed via nylon or plastic cable ties in substandard installations. The use of cable ties has been outlined in the CEC Guidelines such that “Plastic cable ties are not suitable for cables in exposed situations. They can also chafe the cables.” [31]. The ITO just stipulated that cable ties were not to be used, but left options open for other products that could be used if it suited the application for 20 years, and were compliant with Australian Standards (AS5033, 3.4.2) [4].

The options presented were:

- Nylon cable ties – argued to have life of 15 years in UV situations [32].
- Metal cable ties – with a potential to cut the insulation on the cable and therefore presenting a potential fire risk.
- Flexible PVC conduit and fittings – fixed to the frame via screws in enough position to support the weight. This was the best solution presented. However,

the PVC conduit may be rated up to 50°C, which would reduce the life-expectancy in UV light as the temperatures would be expected to exceed this [33].

- Halogen-free fire-resistant temperature-stable (HFT) conduit – was asked for as a solution as it was UV rated, and conditioned for the appropriate temperatures [34].

The final installation has included both the flexible PVC conduit and the HFT conduit. The certificates detailing the UV stability have been requested for compliance with the CEC Guidelines and AS5033.

3.10 Patch Panels

The patch panels were to be design such that a power analyser could be used to accurately record current and voltage of the systems before and after the inverters.

At the time of writing the patch panels were yet to be designed by the subcontractor. Some of the considerations are mentioned in points 5.7 and 4.8. Another consideration of the AC and DC current levels should also be noted. There were three methods recommended by the manufacturer for recording current in this model of power analyser.

3.10.1 Current Transformer

A current transformer (CT) would be required where the current was expected to be above 30A. However, as none of the currents from the inverters are expected to exceed that limit this was not a recommended option.

Additionally, the use of CTs would pose a significant safety hazard if the CT was not shorted across the terminals when the power was applied. In that case the CT would have an extremely high voltage between its terminals.

3.10.2 Series Connection

In the use of a power analyser in series it was recommended by the Murdoch Technician, who had relevant experience, that the AC and DC currents should be protected by fuses. These fuses would need to be rated at less than 30A, and be of the ultra-fast and sensitive type. However, this may not succeed as a fuse rated at less than 30A may still allow for a current greater than 30A before the fuse melted.

In the technician's experience any currents above 30A would damage the equipment and may cost 2/3 of the replacement price for repairs.

3.10.3 Shunt Connection

Were a shunt used, it would require appropriate sizing for the current it was representing and the voltage window for the power analyser. The external shunt inputs for the power analyser were in discrete ranges of 50, 100, or 200 mV, but needed to be within 140% of the 200 mV range [35].

Any resistance-based shunt should be connected to the negative (earthed) cable to reduce the risk of electric shock from higher voltages at the shunt. However, this would not be possible on DC cables where the array's negative is not earthed.

The shunt voltage should be designed for the 50 mV range (if possible) and a higher current range than the maximum short circuit current. The 50 mV voltage range would allow for the scale to be increased on the power analyser in higher current situations and provide the least resistance (losses).

3.11 The Final Design

The final design of the PV systems has been illustrated in Figure 3 as a flow diagram that also incorporates the ESB system. For more detailed designs line diagrams have been created and can be seen in Appendix G.

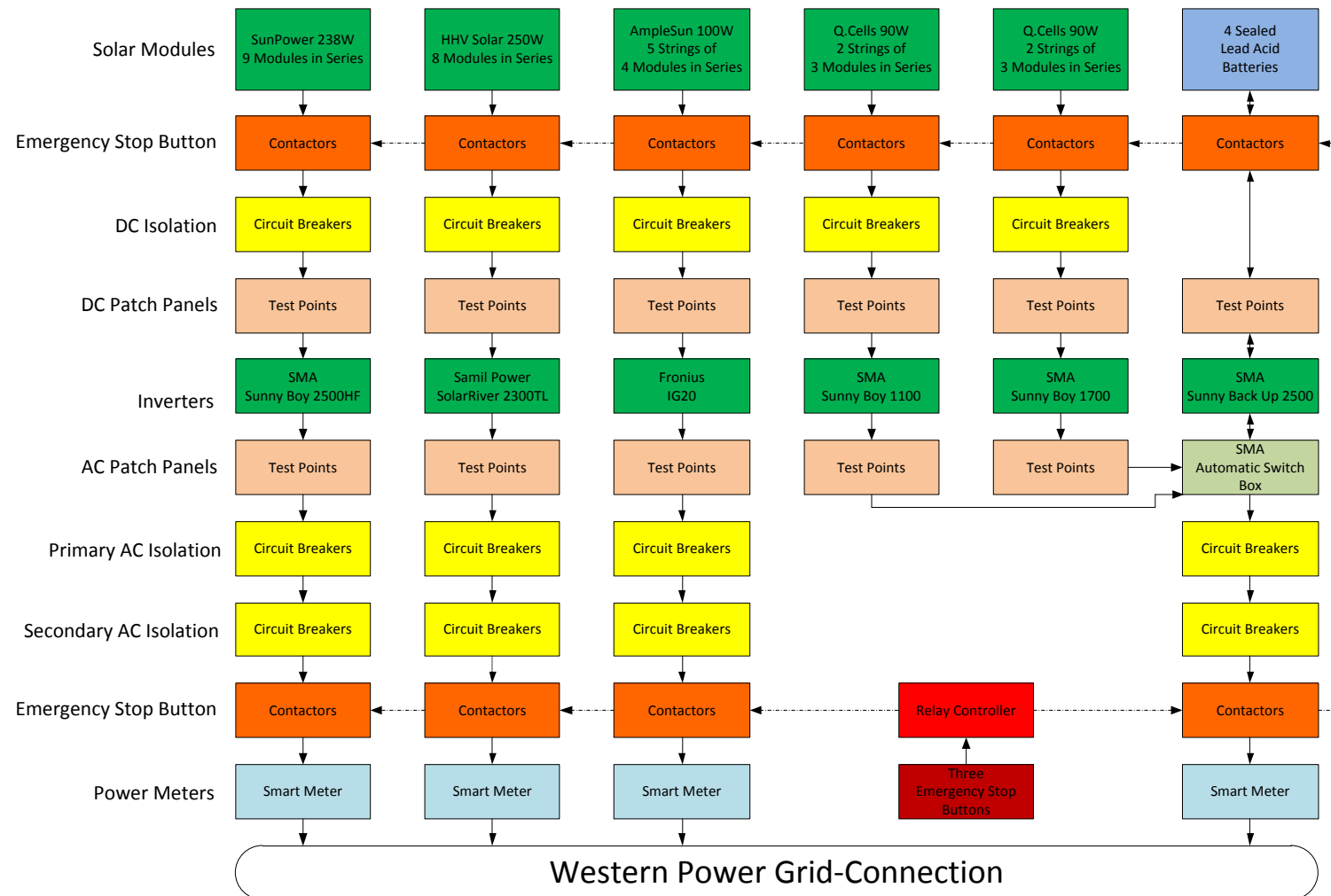


Figure 3: Estimated final flow and emergency stop button diagram for the installation.

Chapter Four – Invitation To Tender

4 Drafting a New Invitation To Tender (ITT)

There were additional funding requests made by the contractors in relation to the wording in the ITO. It was made apparent in later meetings that the contractor did not provide the subcontractor with a copy of the ITO prior to estimating a cost for the installation. This could not be foreseen by the University as it would not have had communications with the subcontractor until the contract was awarded. However, the intent of the ITO was believed to be clear until questions were raised.

For this reason this report has included a modified ‘Invitation To Tender (ITT)’ in Appendix H as a suggestion for future PV projects at the University. A summary of the main reasons for changes are now being detailed.

4.1 Temperature

4.1.1 Ambient

The ambient temperature should be stated for design purposes outside the building. The Australian Bureau of Meteorology’s closest weather station is at Jandakot Airport (less than 4 km away from Murdoch) where the ambient temperature has been recorded since 1989. A maximum temperature of 46.6°C was recorded on February 23, 1991 [36]. It has now been stated in the ITT to design for 50°C ambient temperature.

4.1.2 Objects in Direct Sunlight

Items in direct sunlight should have a higher temperature rating than the ambient. This is due to the higher energy content of direct sunlight. The conference notes from National Renewable Energy Laboratory (NREL) gave an indication to expect 30°C above ambient in direct sunlight for objects well ventilated [37]. Another study at the University indicated a temperature of 77.1°C for roof mounted modules [38]. However, the ventilation in other applications may be poor and a revision of the maximum temperature to design for should be revised in each project.

4.2 Clarity of ITO Requirements

4.2.1 Installation of the Automatic Switchbox M (AS-Box), Sunny Backup 5000 (SBU5000), and Sunny Boy 1100 (SB1100)

It was not clear enough that the AS-Box, SBU5000, and SB1100 were to be installed in response to the ITO. The language used in the ITO was:

- Point 3.3 – “To be installed”,
- Point 3.2 – items to be “integrated”, and
- Point 3.4.18 – Under ‘Specific Requirements’, details “The PV Training Facility will integrate existing equipment owned by Murdoch University into the installation...”

The understandings of the points were that the equipment was already installed and additional equipment needed to be installed around it. The terms should be made clear where the items need to be ‘supplied and installed’, or the ‘installation and integration of existing equipment’. These points have been clarified in the Scope and the Installation Requirements of the ITT.

In this instance, additional funding was met equally between the contractor and the University.

4.3 Inverters

4.3.1 Sunny Boy SB1100

Similar in wording to the previous point, 4.2.1, the installation of the SMA SB1100 needed to be detailed clearly and that it must be ‘installed’ in the Scope of the work and Installation Requirements. This was not addressed as part of the tender response, but was requested at a later stage.

4.3.2 Inverter Layout

The layout of the inverter at their intended positions on the wall was not requested in the ITO. However, this was important part of the design as the University would be displaying the final configuration to prospective students. There were various locations discussed for the inverters which considered:

- Ventilation around the inverters.
- The placement and location of the inverters; e.g. the SBU 5000 should be positioned as close to the battery bank as practicable.
- Sufficient space available for all the components.

4.3.3 Communication and Data Recording

The inverters had appropriately been requested with capabilities of measuring and recording system performance. The method used should be stipulated as part of the response to the ITO. Ideally RS 485 or Bluetooth should be used for all the inverters. This would allow remote access to the inverters or allow for a sufficient length of (RS 485) cable to store the computer at a different location to the inverter.

4.3.4 Password Protection

The inverters were planned to be located in a hallway accessible to the public. This has the potential of the inverters being tampered with if they were not password protected.

4.4 Arrays

4.4.1 Specifying the Size of the Arrays

The array should be specified as a minimum kWp size so that it is unambiguous to the supplier. For the arrays being installed in this project would need to be 2 kWp as there should be ample space on the frame to mount that size of system. If the contractor could not provide this minimum specification then this would be negotiated.

4.4.2 Mounting Rail for the Modules

The design of the array frame was replicated from a similar arrangement on the roof of the RISE building. This design attached the modules via a moulded U-shaped plastic bracket that was screwed into the modules at the ends of the clamp and the cylindrical rail was cupped inside the clamp (Figure 4). This design was chosen by RISE specifically for the leakage current experiments and would not be appropriate for general applications as they did not provide sufficient conduction to the frame. However, this aspect was not mentioned specifically in the ITO.



Figure 4: U-Shaped module mounting bracket

The ITO detailed for the installation of four grid connected PV systems and it would be mounted onto a frame [2]. Neither the U-shaped clamps nor type of mounting rail provided with the frame were mentioned in the ITO. The ITO did not mention the size or scale of the frame in which it should be mounted to, but preliminary drawings of the frame were included as attachment to the ITO.

This inclusion of a new rail was successfully argued as an additional cost to the contract as the intended U-shape clamps were no longer available on the market, and that the specifically designed, Antai New Energy, mounting system for the PV modules must be used for the wind loading and cyclone rating [19, 39]. However, it was also argued that the array would be mounted to a surface as part of the installation, and therefore the additional costs of the rail were met equally by the University and the contractor.

The type of mounting system is now outlined in the ITT (Appendix H). The option of using the rails provided with the frame has been stated, but whichever option is used it must be stated in the tender response.

4.5 Backup System

4.5.1 Battery Enclosure

The construction of battery enclosure has been addressed in 3.6 of this report. However, when writing the ITT, further consideration was given to location of the battery enclosure. The enclosure will be in direct sunlight during daylight hours and should be designed with the following considerations:

- Compliance with the Australian Standards.
- Whether the temperature inside the enclosure will exceed ambient temperature or a set maximum temperature inside the enclosure.
- Whether the ventilation should be either mechanical or natural.
- The maximum space available for the battery enclosure.
- Access to the batteries.
- A drip tray is required, and should include its capacity.

4.5.2 Cable Sizes and General Power Outlet(s) (GPO)

The expectation of the battery system should be stated in the ITO. This should have been done in relation to the DC cable size from the SBU5000 to the batteries, and the rating of the GPO(s). A request was made by the University after the contract was awarded detailing that the system should be rated for its full potential. The request was made for the GPO(s) to be rated for the maximum 35A of the SBU5000, which could increase the current significantly in the battery cable even for short periods. For estimated battery efficiencies, see point 6.1.3 of this report. The maximum load of 35A would draw approximately 200A from the battery with the efficiencies estimated for the SBU5000 and battery system. However, the SBU5000 has a maximum allowable cable size for a battery bank of 70 mm², which according to Table 4 of AS 3008 details that a

cable of 70 mm² has a current carrying capacity of 185A [40]. This means that it may be unsafe to operate the system with a maximum load of 35A.

For this reason, any future systems should estimate the current draw on the batteries and state the (minimum) cable size required. The ITT now reflects a cable size of 70 mm².

4.6 Cable Protection

4.6.1 Cable Trays

Provision of cable trays was not included in the ITO. It seemed understandable, on behalf of the University, that the company installing the cables would install cable trays to envelop all array cables from the modules to the inverters. However, on reflection this was an oversight, as a company would not know if the cable trays would be installed as part of the fabrication of the frame.

4.6.2 Cables Exposed to Ultraviolet (UV) Radiation

It could have been made clearer that the cables exposed to direct or indirect UV radiation should have additional protection in the form of UV-rated conduit, duct, insulation, or cable tray, despite being stipulated in the CEC guidelines and Australian Standards [4, 31]. It should have been specified that any cables, conduits, ducts, and cable trays should be rated for temperatures at least 50°C ambient temperature and 80°C in direct UV (see 4.1 above for temperature definitions).

It should be made clearer in any future ITO that conduit (etc.) exposed to UV light should be fixed to the frame (or rails) via stainless steel cable ties. Alternative methods could be used, such as, screwing the stainless steel clips, but would require approval by the University first.

4.7 Emergency Stop Buttons (ESBs)

Provision for ESBs was not included in the ITO but was requested at a later stage in the project. It became apparent that there would be limited protection during experiments for staff and students and that an additional safety device would be required (see 3.8 for more details on the limitations of the system).

4.8 Patch Panels

The request for patch panels was made in the original ITO (point 3.4.19) [2]. The request did not stipulate all the requirements for the test points for what the University would require. These patch panels needed to be designed, constructed, and installed as

part of this ITO. They also need to be installed behind the relevant system protection so that they could be isolated from power in case of an emergency.

The patch panels should have covers preventing access to the terminals outside of a supervised laboratory. These covers should prevent access to a (minimum) International Protection rating of IP41, and be lockable in the covered (closed) position [41]. This protection level states:

- IP41 – “Protection of persons holding small tools or wires (larger than 1mm diameter)”
- IP41 – “Protection against drops of water falling vertically”.

As some inverters come with more than one string input, the ITO would need to reflect this. Each string input to the inverter should have its voltage and current available on the test points.

When connecting banana plugs or Bayonet Neill–Concelman (BNC) connectors then there is potential for an electric shock, so the patch panels should be isolated before any connections are made. This is to protect the person from accidental electric shock and protect the equipment whilst being connected. However, if a person inserts a metal plug into the connector, and if the person is touching the exposed connector as it is inserted, then there is a high chance of electrocution. For this reason the banana plug connectors should be of the type that allows sheathed connectors.

4.9 Junction Boxes

In this project it was expected that junction boxes would be installed outside, beneath the arrays. These junction boxes may be made out of polyvinyl chloride (PVC) or another similar material. As they would be exposed to direct or indirect (reflected) UV radiation, they should be rated for this exposure.

The junction boxes should also be rated for rough weather conditions, e.g. strong winds with rain. Therefore, the junction boxes should have an IP65 rating, which details [41]:

- IP65 – “Complete protection against entry of dust”.
- IP65 – “Protection against a low pressure jet of water from all practicable directions”.

This is a requirement of AS 3000, 1.4.51 and 3.3.1, and is defined in AS 60529 [42, 43].

4.10 Schedule and Documentation

4.10.1 Meetings

The new ITT has outlined the necessity for meetings prior to construction starting, as this was not stipulated in the original ITO. The meetings would address the design of the installation prior to work starting in this project, as many aspects of this system were not designed until a few days before work started. This left little time for corrections to be made, e.g. layout of the modules on the frame.

A minimum of three meetings would be necessary, which would address the following:

- An initial site visit (if not already completed) and to discuss the specification proposed in the winning tender response.
- The design presented two weeks prior to work starting with any revisions from the initial meeting. The design should detail:
 - A line diagram of the entire system after the AC grid connection of the existing Building's infrastructure;
 - Module configuration behind each inverter, detailing:
 - Number of modules per string,
 - Number of strings, and
 - Whether string protection is required.
 - Cable sizes and types to be used for all AC and DC wiring;
 - The design of the patch panels, including:
 - A line diagram of the electrical configuration,
 - The size of shunts if used,
 - The current transformers (CT) if used, and
 - The protection devices used (e.g. fuses).
 - Surge protection device (SPD) configuration and rating for integration into lightning protection system;
 - Method for equipotential bonding of modules and integration into the lightning protection system;
 - Types of conduit, ducts, insulation, cable trays, junction boxes, and cabinets used in the system;
 - Datasheets of all the inverters and modules being supplied under the contract. Any additional datasheets or certificates requested by the University should be made available within two working days.

- A meeting at which the University will respond to the design presented, with any amendments being incorporated into the installation. This meeting should include all parties involved with the design, installation, and supply of products.

4.10.2 Reporting

The ITT has now outlined specific details that need to be reported in a tender response. These included the detailing of all contractors or subcontractors involved in the project, and their level of involvement (e.g. designing, installing). This was requested to determine the level of expertise being brought into the project. Additionally, this may highlight potential conflicts of interest in the tender process. For example, a subcontractor may have already sourced employment of a (University) project member.

This condition extends to notifying the University of any new contractors or subcontractors involved with the project. This would also be required for site inductions if they are intending to work on site.

All the contractors and subcontractors involved in the project must be made aware of the requirements of the ITT. This is to prevent the contractor from withholding vital details in outsourcing their responsibilities for the cheapest possible price.

Chapter Five – Monitoring Equipment

5 Monitoring Equipment

5.1 Background

There are many different products on the market to measure and record the local conditions at the PV arrays. The accuracy of the monitoring equipment was a major deciding factor in this configuration, as this data would be intended for use in published papers.

The conditions need to be recorded such that they adhere to IEC 61724, *Photovoltaic system performance monitoring*, which determines the minimum equipment requirements for recording data [44]. This outlined:

- **Irradiance** – “The accuracy of irradiance sensors, including signalling conditioning, shall be better than 5 % of the reading.”
- **Ambient air temperature** – “The accuracy of temperature sensors, including signal conditioning, shall be better than 1 K.”
- **Wind speed** – “The accuracy of the wind speed sensor shall be better than 0.5ms^{-1} for wind speeds $\leq 5\text{ms}^{-1}$, and better than 10% of the reading for wind speeds greater than 5ms^{-1} .”
- **Module temperature** – “The accuracy of these sensors, including signal conditioning, shall be better than 1 K.”
- **Voltage and current (AC and DC)** – “The accuracy of the voltage and current sensors, including signal conditioning, shall be better than 1% of the reading.”
- **Power sensors** – “The accuracy of power sensors, including signal conditioning, shall be better than 2% of the reading.”
- **Sampling intervals** – “Sampling intervals for parameters which vary directly with irradiance shall be 1 min or less.”

The recording devices should adhere to the limits of IEC 61724. Exceptions may exist where the device’s calibration may be significantly altered during operation, and where these devices are not recalibrated but replaced with a new device. Therefore, it is recommended that where data shows unexplained behaviour, the tests should be reproduced or the equipment recalibrated after the recording period.

For a price estimate of the monitoring equipment proposed, see Appendix I.

5.2 Recording Interval

The project outlined that the data would need to be recorded at 1 second intervals. On further discussions with Dr. Calais it became apparent that this data would be used for recording irradiance during cloudy conditions and therefore faster recording time than 1 second may be required.

There was some literature relating to the issue of recording cloud cover or recording data in 1 second discrete time intervals. In particular, an article by Burger and Ruther investigated the matching of inverters to PV arrays to optimise the inverter size based on their location, ambient temperature, inverter operating temperature and solar irradiation distribution characteristics. They found that higher inverter temperatures, greater than 75°C, could reduce power by 30% (from nominal) in high irradiance conditions. It is expected that this would reduce the expected life of an inverter through electronic component stress [45]. They found considerable energy losses where undersized inverters limited the power generated in high irradiance conditions.

Relating this to the CEC *Design Guidelines*, which indicates that the design should follow the manufacturer's recommendation for sizing an inverter, failing that, the guidelines outlines an example that the inverters should be matched to 80% of the manufacturer rating of the array [46]. The 20% is to compensate for the derating factors from dirt, temperature, and manufacturers tolerance.

There are further research opportunities in recording 1 second intervals that could prove useful in designing PV systems.

5.3 Climate Data

Initially, configurations were investigated that combined multiple pieces of equipment into one device. This included the Vaisala weather station (model WXT520) which incorporated barometric pressure, irradiance, wind (speed and direction), rain fall (quantity and intensity), and ambient temperatures. Another benefit of this type of equipment would be exposing students to a greater range of technology on the market. However, these products did not comply with IEC 61724 [44, 47].

There were benefits in choosing individual pieces of equipment. These included compliance with IEC 61724, but also individual item recalibration and having reserve items on standby. Otherwise, for example, if the Vaisala weather station failed or required servicing or recalibration, then large gap(s) would appear in the data.

5.3.1 Anemometer

The anemometer proposed for measuring wind speed was:

Company: NRG Systems

Model: #40C + MEASNET

This anemometer was chosen as it was sold with a unique calibration certificate from MEASNET (Measurement Network of Wind Energy Institutes). A calibration certificate would have been required if it was received with a general certificate for that model, which would increase the cost significantly. This advantage for the #40C low cost meant that a new anemometer could be purchased after one year instead of recalibrating. The year old anemometer could be added to the teaching equipment for the Renewable Energy Engineering course where students could practise programming the device through a data logger.

5.3.2 Wind Vane

A wind vane was not stipulated as a requirement under IEC 61724, but would be incorporated for potential research opportunities with the solar array. The wind vane chosen was:

Company: NRG Systems

Model: #200P

This may need reviewing at a later stage depending on the required accuracy of the data.

5.3.3 Ambient Temperature

An Envirodata (TA50) was a solution for measuring ambient temperature. This has an uncertainty of 0.2°C from -10°C to 30°C, and a yearly drift of 0.1°C [48]. The advantage of this was that it would not need replacing or recalibrating yearly and it complied with IEC 61724, which details accuracy greater than 1 Kelvin, including signal conditioning. However, a local company could provide a calibrated resistant temperature detector (RTD), PT100, with accuracy greater than 1 Kelvin, for less than a quarter of the price of the Envirodata (TA50), which could be recalibrated or replaced every year for a similar cost [49].

5.3.4 Module Temperature

The module temperatures could be recorded for future research opportunities. The RTDs outlined in 5.4.3 could be installed on the back of 8 modules to measure shaded and unshaded modules temperatures. The placement of the RTDs should be in

accordance with IEC 61829, Method A, where they should measure the “temperature at the centre of the back surface of the selected central module(s)” [50].

5.3.5 Pyranometer

In order to measure data accurately (<5% uncertainty), a single (first class) thermopile pyranometer was needed [44]. However, thermopile pyranometers generally have a response time of 3 to 12 seconds depending on the model. This would not be acceptable for measuring data at 1 second intervals, as the irradiance variations could be as much as 275W/m^2 per second and would therefore require a response time to be similar [51].

A paper released by NREL provides a performance (percentage error) review of some of the most widely used pyranometers on the market. These included the Kipp & Zonen SP Lite, a similar model to the SP Lite2 that has been recommended for sampling 1 second irradiance data in this report (see 5.4.5).

The paper suggests that the “SP Lite pyranometer is comparable to that of much more sophisticated instruments...” which has a percentage error “within 1-2% of the reference data on average” [52]. The percentage error was uncorrected for cosine error or temperature.

As a solution, a PV cell type pyranometer for measuring the data at 1 second intervals. The PV cell type pyranometers have a response time in the nanoseconds, which would allow for increased sampling time if needed at a later stage. However, the PV cell type pyranometers have a higher uncertainty compared to the thermopile type pyranometers and could be greater than the 5% required under IEC 61724.

The solution proposed is to use two pyranometers for measuring the irradiance data: the PV cell type pyranometer for measuring at 1 second intervals and the thermopile type pyranometer for correlating the output of the PV cell type pyranometer.

Thermopile pyranometer

Company: Middleton Solar

Model: EQ08

PV cell pyranometer

Company: Kipp & Zonen

Model: SP Lite 2

The PV cell type pyranometer has a temperature derating factor of $-0.15\%/^{\circ}\text{C}$, which should be monitored with an additional RTD (PT100).

5.4 Data Loggers

The preferred data loggers used at Murdoch in the Renewable Energy Department for recording and sending data would be dataTaker loggers. For this reason the DT80 data logger was investigated in conjunction with an expansion module (CEM20). This would have been sufficient under standard recording conditions, i.e. 15 seconds to 15 minutes, with a multiplexing sampling frequency of 25 Hz [53]. This would ideally allow for a sampling time of 0.6 seconds (1.67 Hz) across each channel. However, with a multiplexer the sampling time is dependent on the time it takes for each channel to be recorded in sequential order. Even with an ideal sampling time of 0.6 seconds it would be 9 seconds (0.11 Hz) to complete a full rotation and return to the same device. This would fail to meet the requirement of recording irradiance with a 1 second sampling time. An alternative solution was needed.

The upgraded model to the dataTaker DT80 was the DT800, which has a multiplexing sampling time of 1 kHz to 100 kHz [54]. This would be more than adequate for a 1 second sampling time.

An alternative to the dataTaker would be a 4-slot Integrated Controller and Chassis by National Instruments (NI). The device has a sampling time of 400 MHz, which may be limited by the input modules [55]. The input module needed to record at 1 second intervals or greater would be the NI 9205, which has a sample time of 250k samples per second (or kHz) [56]. The advantage of using this piece of equipment is that students from the University studying Instrumentation and Control could incorporate LabVIEW into the system to provide a “live” analysis and feed from the weather station.

Either type of data logger has the “FTP Push” function, which would send the data at the end of each day to a server in the form of a comma delimited file. The file could be opened with Microsoft Excel for validation.

The data logger would need to be housed outside in the middle of the array beneath the modules. The enclosure will need to be kept at less than 50°C at all times and therefore would require mechanical ventilation.

5.5 Monitoring Inverter Performance

The inverters installed for each array have communication capabilities through RS 232/ RS 485 connectors. A NI input/output (I/O) card has been sourced from the RISE with four RS 232/ RS485 ports [57]. The RS 485 capability with SMA software allows for the SMA inverters to be daisy-chained to one port of the card. Two out of the other three other ports would be for a Fronius IG20 inverter and a SamilPower SolarRiver 2300TL, and leaves one spare. Both the Fronius and SamilPower inverters have their own specific software that should be used for recording data. Both the software and I/O card would require a computer to run.

The latest version for the I/O card driver may need to be downloaded from NI.

5.6 Monitoring AC and DC Voltages and Currents

In order to measure both the AC or DC voltages and currents either side of the inverters, a Yokogawa (model WT2030) power analyser has been sourced from RISE. At the time of writing, the method for sampling current through the power analyser was not yet determined. However, if a shunt was used then the following method for recording data should be observed.

The power analyser measures discrete millivolt ranges of 50, 100, and 200 for the external shunts. If the shunt is not rating to the same ranges of the power analyser then a conversion should be applied. For example, if a shunt has a 10A range which is equivalent to 60 mV then a scaling fraction could be used to convert to the appropriate current [35].

$$\frac{\text{Shunt Current Range (A)}}{\text{Shunt Voltage (mV)}} \times \text{Power Analyser Range (mV)} \\ = \text{Current Measurement (A)}$$

Example: $\text{Current Measurement (A)} = \left(\frac{10}{60} \text{mV}\right) \times 50 \text{mV (setting range)} = 8.33\text{A}$

The scaling factor can also be programmed into the power analyser for the correct readout.

Chapter Six – Performance Ratio

6 Performance Ratio

The system information has been based on the components delivered or installed thus far. Minor changes from the final specification may be required on completion of the project. The system that has been estimated has incorporated the main components as illustrated in Figure 3.

6.1 Manual Estimate

The method used for the derating factors are outlined in the Australian Standards [20]. The NREL Performance Ratio and the CEC calculation methods were used in this report [37, 58]. The PR is:

$$PR = \frac{Y_f}{Y_r} \quad (\text{Eq.1})$$

Where

Y_f - The specific yield of the system, in kWh.

Y_r - The reference yield of the total in-plane irradiance, in hours.

The method has been detailed in Appendix J, where Y_f was the same in the NREL Performance Ratio and CEC calculations. However, there are two methods for calculating Y_r , which were:

Method One

$$Y_r = \frac{P_{array,STC} \times H_{tilt}}{G_{STC}} \quad (\text{Eq.2})$$

Where

$P_{array,STC}$ - Rated output power of the module under standard test conditions, in watts.

H_{tilt} - Daily irradiation on the tilted plane, in peak sun hours (PSH).

G_{STC} - Solar radiation under STC, 1000W/m².

Method Two

$$Y_r = H_{tilt} \times \eta_{pv} \times A_{pv} \quad (\text{Eq.3})$$

Where

η_{pv} - The rated efficiency of the PV module under STC, dimensionless.

A_{pv} - The total area of the PV array, m^2

Method one was used in the manual calculation.

6.1.1 Inverter and Module Performance

The data used in this estimation, unless otherwise stated, was based on latitude -32.5 and longitude 115.5. This was the closest estimation to Murdoch University's latitude (-32.06) and longitude (115.8) [59]. The other parameters for the manual estimation were calculated on the following basis:

- **Shading** – The shading estimated in the calculations were from data provided by Dr. Calais and Dr. Pryor, which used the Solar Pathfinder photographs taken for ENG421 on March 8, 2011 (Figure 5, Appendix K). These were taken approximately 40cm above the roof plane [60]. The Solar Pathfinder approximates the amount of direct radiation affected by shading, whereas the simulation also evaluated the amount of diffused radiation unaffected by shading.

New Solar Pathfinder photos were desired for the different heights of the array to include both the top and bottom edge of the array or in the centre of the each array. However, this was not done as it required a working at height permit.

- The positions used in the estimation from the Solar Pathfinder photos were:
 - Ample Sun modules best lined up with position 5.
 - SunPower modules best lined up with position 6.
 - Q.Cells modules best lined up with position 6.
 - HHV modules best lined up with position 1 or 2.

- **Sun hours** – A daily PSH was taken from 'Monthly Averaged Radiation Incident On An Equator-Pointed Tilted Surface' (tilted at -32°) [61].
- **Temperature** – Data was not available for average temperature during daylight hours. Therefore, temperature derating was based on (total) average daily

temperature at 10m. The estimated temperature of 30°C above ambient was used as the modules are well ventilated on their frame [37].

- **Modules and inverters** – The component parameters were sourced from datasheets and manuals through the internet, provided by the supplier, and read from the back of the modules installed [11, 14, 16, 62-67].
 - The Maximum Power Point Tracker (MPPT) was included as part of the inverter efficiency.
 - The inverter efficiency had been approximated respective to the array sizes and DC voltage ranges.
 - Where inverter efficiency power curves were not available the maximum efficiency for the inverter was used.
 - The MPPT voltage range had been considered for the inverter efficiency approximations.
 - A manufacturer's tolerance of 5% has been taken for each of the modules unless it was stated by the manufacturer. A negative efficiency was taken where the manufacturer gave a '±' correction.
- **Cabling** – As stated in the ITO the array cables had not exceed 1% [2]. However, the AC cable to the switchboard was included for each system, which increased the cable derating by 1% for the calculations.

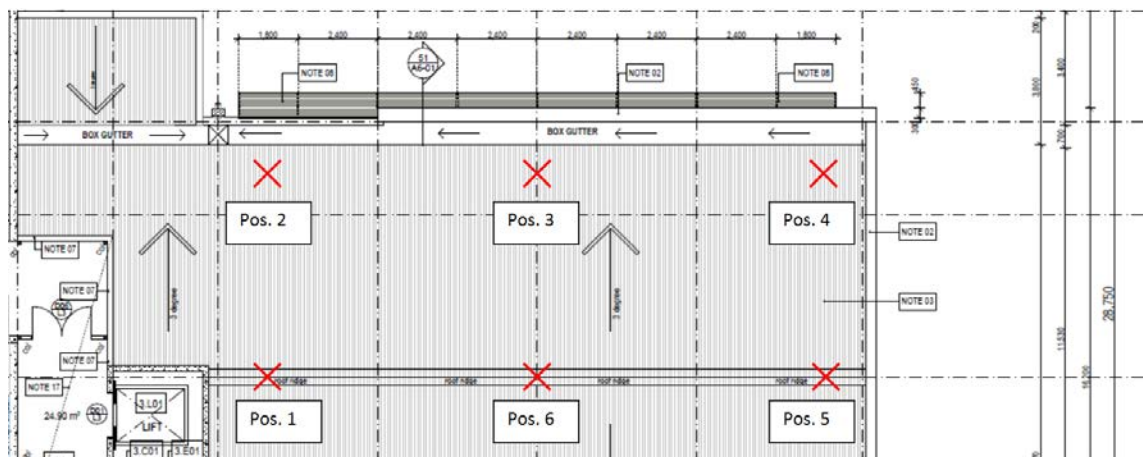


Figure 5: Positions of the Solar Pathfinder taken March 8, 2011 [60].

The results of the PR for the manual estimate can be found in Table 1 and illustrated in Figure 6. The results for the HHV system are significantly lower than the other systems, as that end of the arrays is subject to increased shading from the tree in the early mornings and the building near sunset during the summer period. This is best

represented with Figure 25 in Appendix K. The low performance of the HHV system has affected the overall system PR that can be seen in Figure 7.

Table 1: Manual Performance Ratio of each inverter with its module type and the combined performance.

Month	Performance Ratio (PR)					
	Sunny Boy SB2500HF/ SunPower	Fronius IG20/ AmpleSun	Sunny Boy SB1700/ Q.Cells	Sunny Boy SB1100/ Q.Cells	SamilPower 2300TL/ HHV Solar	Combined Performance Ratio
January	0.764	0.743	0.726	0.723	0.619	0.715
February	0.728	0.763	0.692	0.689	0.698	0.714
March	0.767	0.770	0.730	0.727	0.723	0.743
April	0.775	0.800	0.737	0.734	0.701	0.750
May	0.785	0.805	0.746	0.743	0.672	0.750
June	0.780	0.809	0.742	0.739	0.584	0.731
July	0.783	0.810	0.745	0.742	0.587	0.733
August	0.787	0.810	0.748	0.746	0.724	0.763
September	0.792	0.806	0.753	0.750	0.744	0.769
October	0.783	0.777	0.744	0.741	0.745	0.758
November	0.750	0.750	0.713	0.710	0.653	0.715
December	0.728	0.735	0.692	0.689	0.596	0.688
Average	0.768	0.781	0.731	0.728	0.671	0.736

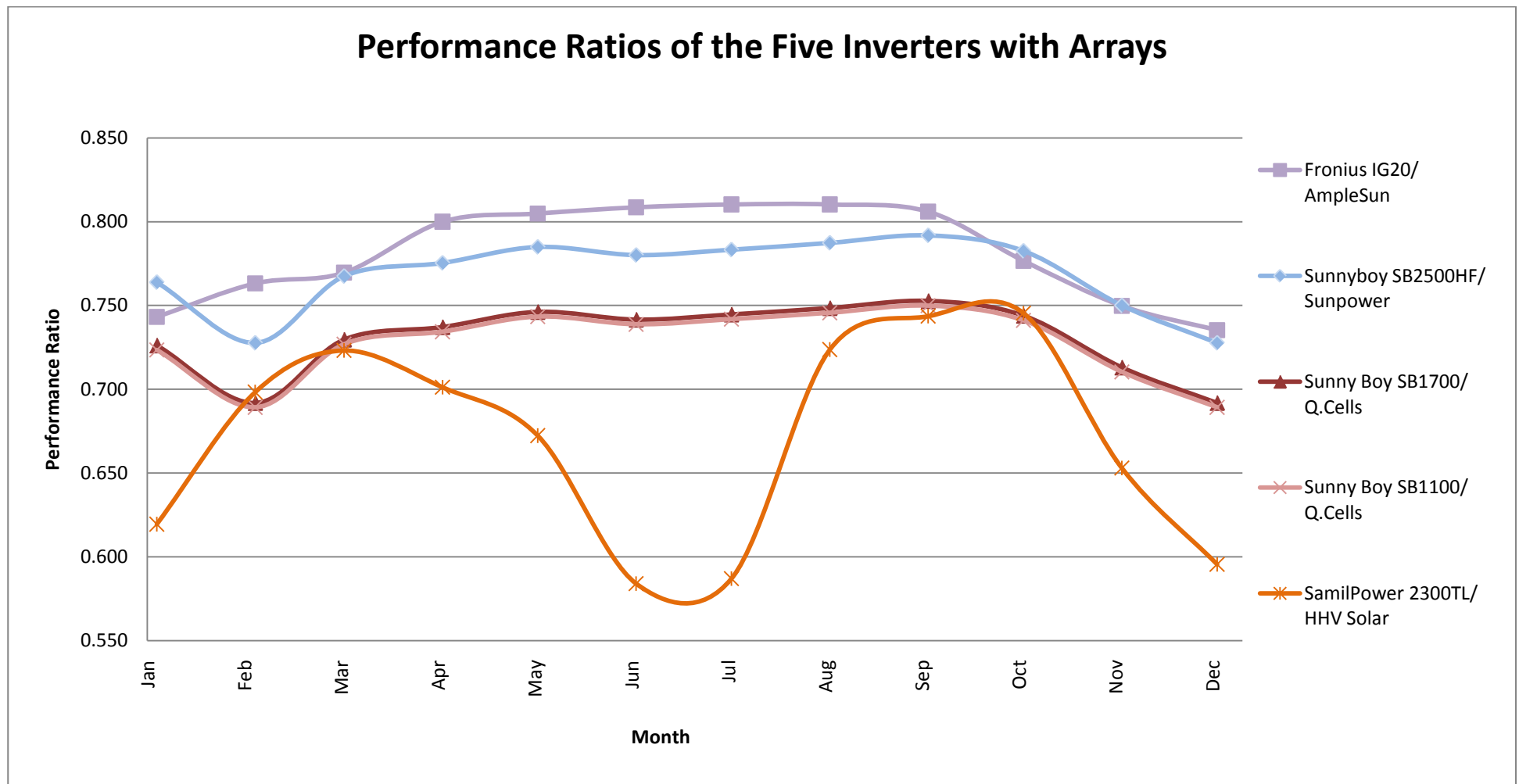


Figure 6: Performance Ratio of each inverter with its array.

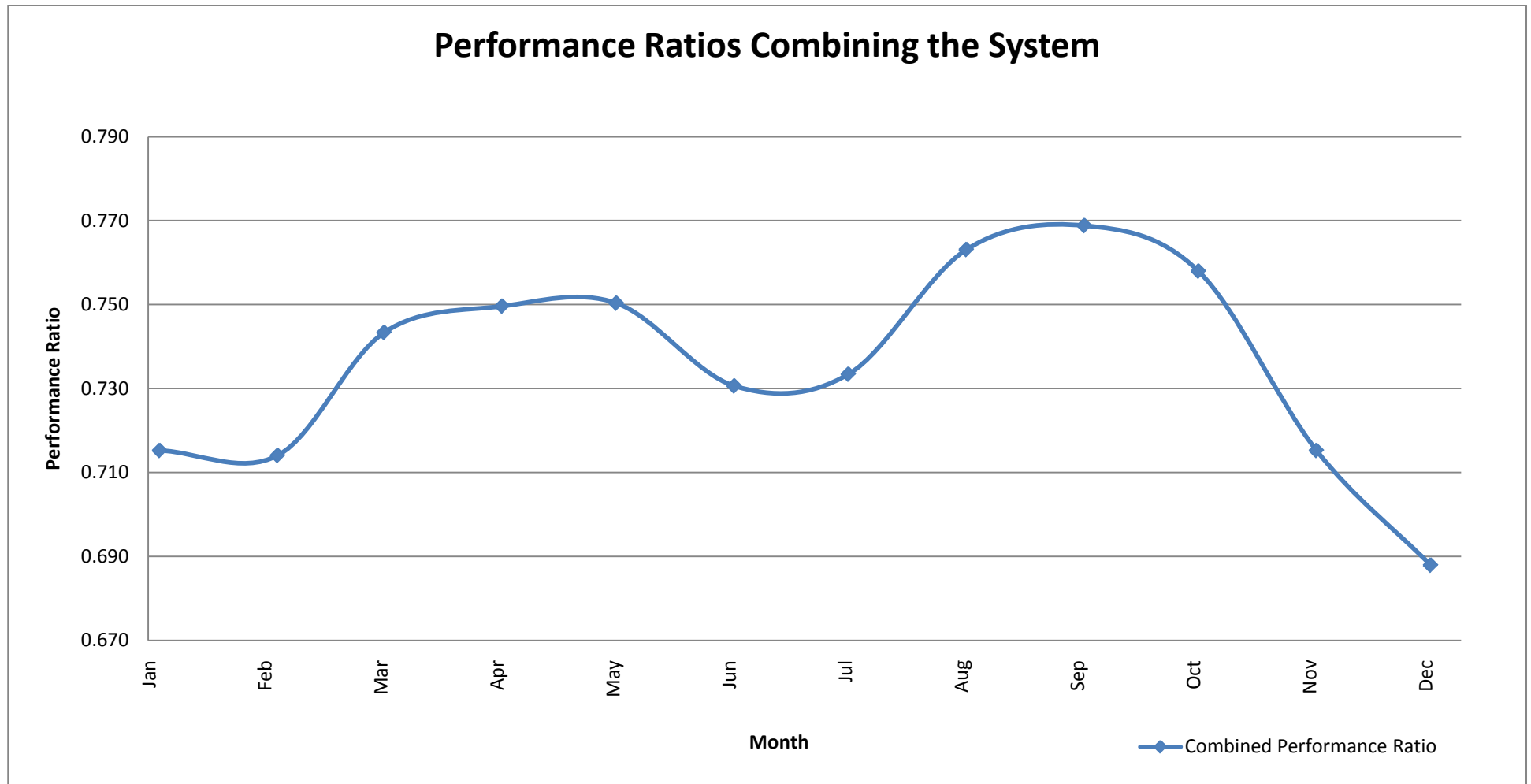


Figure 7: Manual Performance Ratio combining all the PV systems

6.1.2 SBU5000 Performance

The performance of the batteries and SBU5000 is dependent on the following:

- The load being drawn through the GPOs,
- The temperature of the SBU5000,
- The temperature of the batteries,
- The resistance of the battery cable, and
- The duration that the load is above 4000W.

The datasheet suggests a nominal output of 1000W (AC) at 95% efficiency. However, if the load is higher than 1000W (AC) then a derating factor will apply. A derating factor was given in the form of graph from SMA, which is approximately linear after 2400W (AC) [63]. The gradient of the line was approximately $-0.001\%/W$ (AC), which was used for linear extrapolation after 4800W (Figure 8). This extrapolation should be used as the maximum efficiency of the inverter after 4800W.

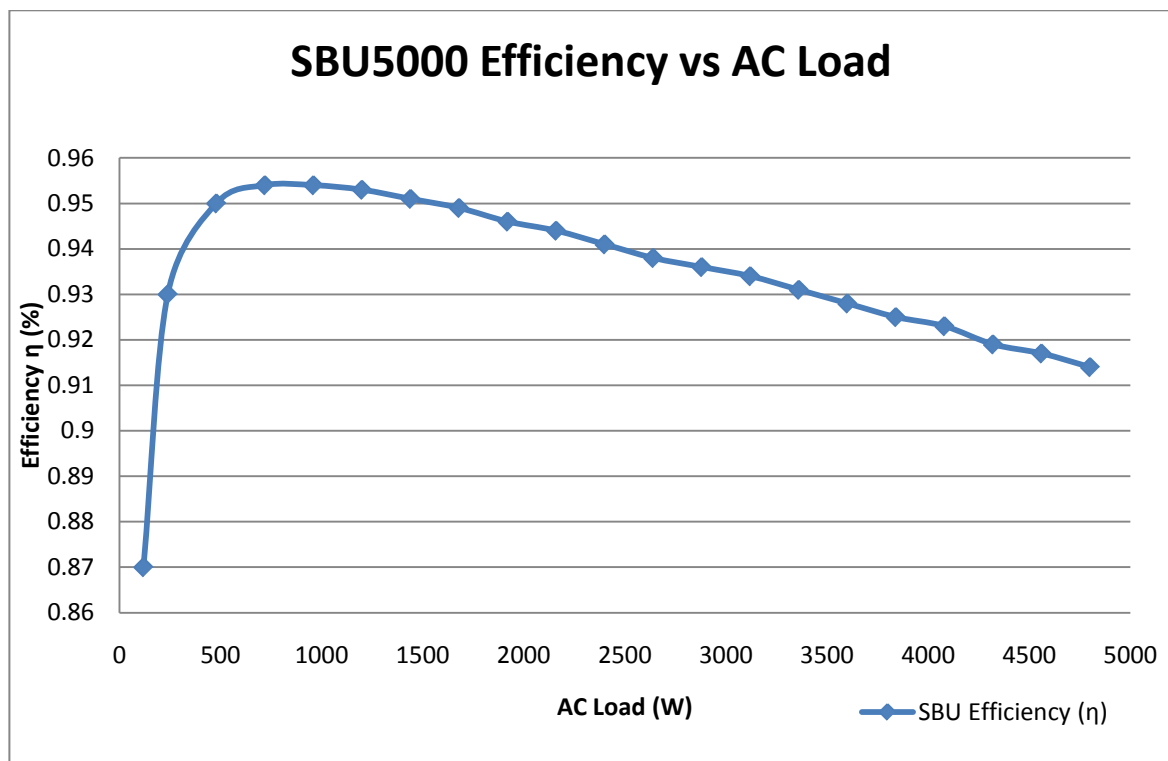


Figure 8: A graph replicating the efficiency curve of a SBU5000 in relation to a 230V AC device (5kW load, 300 A DC Shunt).

The SBU was not designed for higher power loads. The manual details that power above 5000W can only be sustained for short periods:

- 6500W – AC output power for 30 min at 25 °C;
- 7200W – AC output power for 5 min at 25 °C;
- 8400W – AC output power for 1 min at 25 °C [63].

The decreasing efficiency of higher loads affects the current draw from the batteries. The current was estimated up to 200A with an 8400W (AC) load and using the above extrapolation.

6.1.3 Efficiency of the Battery

The type of battery was yet to be specified by the contractor at the time of writing. Therefore, the battery, RITAR RA12-100, has been chosen for this estimate but might not reflect the final configuration of this system.

The RITAR battery datasheet does not include an overall efficiency as the efficiency is dependent on a number of factors, including [68]:

- Temperature,
- Rate of charging,
- Rate of discharging, and
- Depth of discharge or state of charge.

However, efficiency of sealed lead acid batteries could be generalised for between 85 and 95%, depending on the battery, and at 22.2 °C (72°F) [69]. For this estimation the temperature was expected to be closer to 30 °C due to the enclosure's position in direct sunlight. For this reason a general efficiency of 80% was used.

The curve in Figure 8 provides the efficiency of the inverter converting from DC to AC. However, the efficiency of the full wave rectifier was not included in the technical data of the SBU5000 and neither was the AS-Box. The AS-Box was neglected in this estimate as its primary function is to switch between the battery banks (SBU5000), inverters, and grid connection in case of interruptions to power supply of the loads. The SBU5000 has been estimated at 99% efficiency for the conversion from AC to DC as the conversion would be carried out with rectification diodes and a buck converter, which would have minimal losses.

6.2 Computer Simulation

The software believed to be best suited for the simulation was PVsyst as it included shade modelling required for this project. Other simulation software (Hybrid2 and HOMER) did provide performance estimates, but failed to provide the shade modelling needed for this system [70, 71].

PVsyst has been designed to simulate the behaviour PV technologies in near future scenarios. The software enables users to analyse different configurations and system sizes to develop an optimal solution based on the simulation results [72].

The simulation software, like many other software packages, is being continuously improved for better estimations in system responses. Research papers released by the founder Dr A Mermoud are being incorporated into the software. These papers have investigated:

- The behaviours of one-diode models of amorphous, microcrystalline, and cadmium telluride (CdTe) modules [73].
- The characteristics from near (partial shading) objects or far shading seen from the horizon [74].

PVsyst is comparable with other leading software available on the market. In April 2011, PHOTON magazine (Germany) evaluated 20 software packages for simulating solar PV systems. Reference sites were established to compare actual recorded system and weather data with the simulation. It was found that PVsyst underestimated the system's response by approximately 6% using the reference weather data and replicating the system. The simulations were run again using satellite reference data for the locations in the study. It was found that the local instruments underestimated the data by 5 to 10% [75]. This brought the PVsyst simulation results within 0.5% of the system's performance.

6.2.1 Modelling

The system used in this simulation was based on the configuration in Figure 3.

6.2.2 Inputs

PVsyst is still under development at the time it was utilised. This meant that some of the functions were not available, which included setting the simulation period. The default was

only available for 01/01/1990-31/12/1990. However, single daily shadow simulations could be run inside the ‘near shading’ model for any day of any year.

The component database was incomplete for the HHV and Q.Cells modules, SamilPower and SolarRiver inverters. These were entered into the database with information made available through datasheets or from the back of the modules. Specific requests were made to the manufacturers for more detailed information, but were not available at the time of this report.

The simulation was run with synthetic weather data, which was determined, for the Australian continent, from hourly averaged Meteosat data through the SolarGIS database and based on the period from 1994 to 1999 [76].

6.2.3 Near Shading

One of the major areas of uncertainty in this simulation would be from the tree on the north side of the building. This tree may shade the arrays for approximately three months of the year during winter. The shading behaviour of the tree is uncertain as shading would be affected by strong winds. The best model for the one tree was made by layering three trees on top of each other. The parameters of this shading ‘tree’ had been estimated from the shadow path of the simulation model, which was cross referenced with the Solar Pathfinder photos provided in Appendix K [60].

The lift well, building façade (wall), and eave over the doorway into the building were included in the shading model as they appeared in the Solar Pathfinder photo as near shading objects (Figure 9). However, lift well and eave do not have a shading effect as the Solar Pathfinder photos were taken a few metres back from where the arrays are situated. The façade will shade the arrays at the end of each day.

The dimensions of the building, module sizes, and angle of the array have been modelled to the nearest 10 mm and 0.5°. The position of the arrays on top of the building with frame has been modelled to the nearest 100 mm. The ‘tree’ has been modelled with height and distance from the building to the nearest 0.5 metres. The ‘tree’ diameter has been ‘a best estimate’ for each layer.

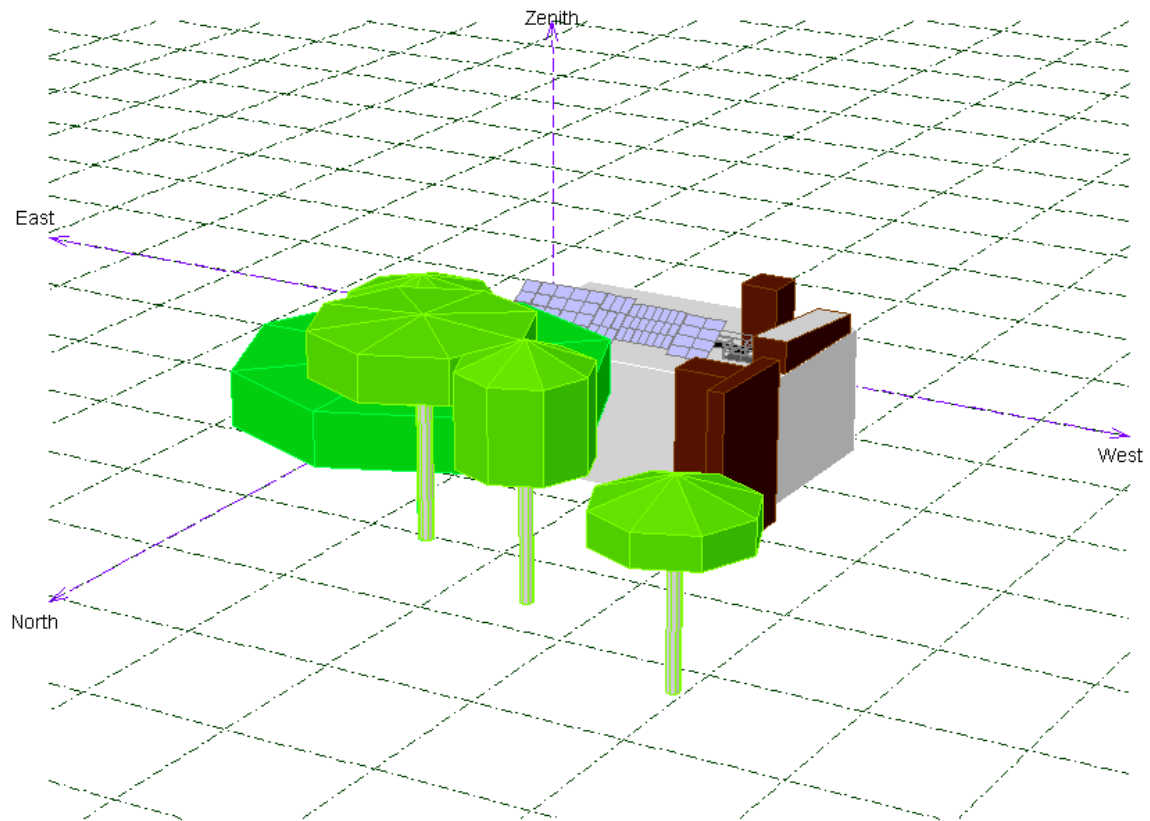


Figure 9: PVsyst near shading model

6.2.4 Far Shading

The horizon does not have any major obstacles that exceed the heights of the trees or buildings included in the near shading model.

6.2.5 Other Parameters

Unless stated, the hidden parameters in PVsyst have been left on the default (Appendix L). Some of these parameters include:

Minimum temperature – the minimum temperature was changed from -10°C to -5°C . The minimum temperature of -3.6°C was recorded at Jandakot Airport on June 16, 2006 [77]. It is highly unlikely that the temperature will be below 0°C during daylight hours.

Wiring losses – The wiring losses have been considered but left at the default of 1.50% despite the ITO requesting array cable losses of less than 1.00%. The extra losses associated with connection losses of the modules, patch panels and protective equipment could increase this value above 1.50%. A way to catalogue these resistances would be to use a mega Ohm meter on each connection.

Albedo – The albedo is a way of estimating the reflectance from surfaces to the array. This generally happens during sunrise and sunset where the sun's array benefits from both direct sunlight and the reflected light. For this simulation the albedo has been set to 0.14 as there are little to no reflective surfaces present during sunrise and sunset. The building is surrounded by trees scattered throughout the car park on the north side of the building. The trees provide a very small amount of reflective surface across the tree.

Linear shading module – A simplified linear shading model was used as the full specifications for the HHV model was not available. Using linear shading precluded the details of the partial shading on each module through their bypass diodes of the cell configuration.

For example, in a real world situation a 72 cell module may have two bypass diodes (one diode for each 36 cells in series), and depending on the partial shading, some cells on both diode may be shaded. This would have a unique electrical property. However, the linear shading model would scale the output of the array linearly depending on the area of the module shaded.

6.3 Results

The PR result combining all the systems (Figure 10, Table 2) illustrates a similar effect to that seen in Figure 7 where the shading affects the HHV modules at the west end of the frame. The combined PR from all systems was 0.748 for the year.

In the near shading animation, the simulation rotated the sun around a fixed point where, in Figure 9, converged to a centre point of reference. It was not clear whether the 'Shading factor table' in Appendix L was generated about this centre point or whether it was generated around a much larger plane of reference. The 'Shading factor table' could be compared as a numerical representation of the Solar Pathfinder pictures. However, multiple simulations were carried out for different points of reference and the results were compared in Microsoft Excel. It was determined that the 'Shading factor table' was not dependant on the conversion point and therefore the shade model behaved consistently.

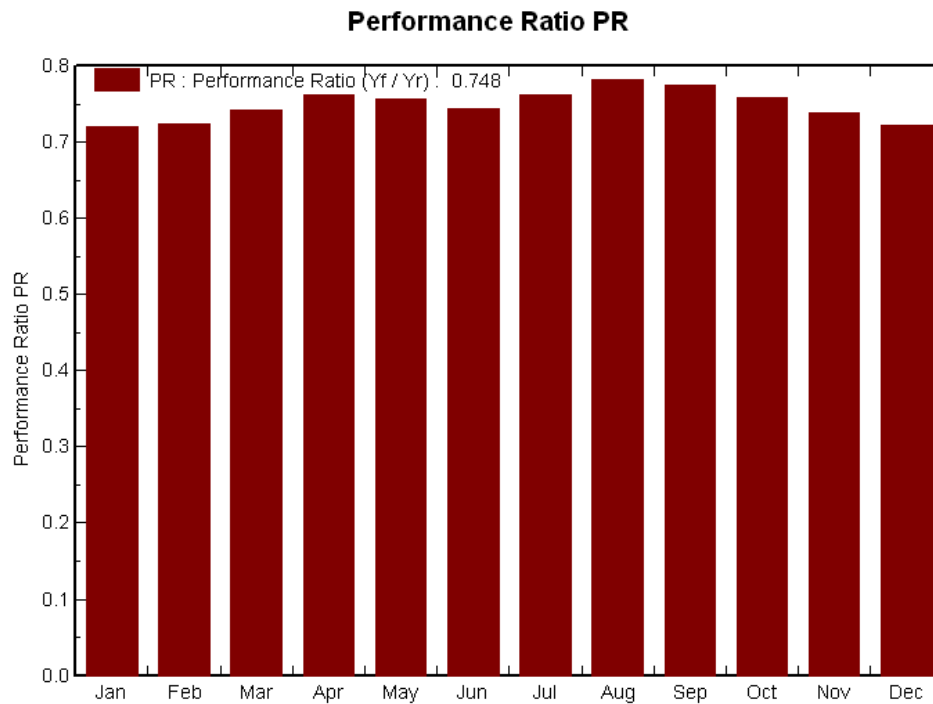


Figure 10: PVsyst Performance Ratio combining all the PV systems

Table 2: PVsyst Performance Ratio combining all the systems

Month	Combined Performance Ratio
January	0.721
February	0.726
March	0.748
April	0.771
May	0.752
June	0.736
July	0.765
August	0.780
September	0.771
October	0.752
November	0.732
December	0.722
Average	0.748

Chapter Seven - Discussion

7 Discussion

7.1 Comparison of the Performance Ratio Results

The general curve of the line in both PVsyst and manual PR in Figure 11 was driven by a few factors. For the summer period (November to February) the lower PR was a result of higher temperature derating factors for the modules. The winter period (June and July) has a lower PR as the arrays are affected by shading of the tree particularly in the morning and the building façade on the north-west side during sunset. This was most evident in the HHV array (Figure 6).

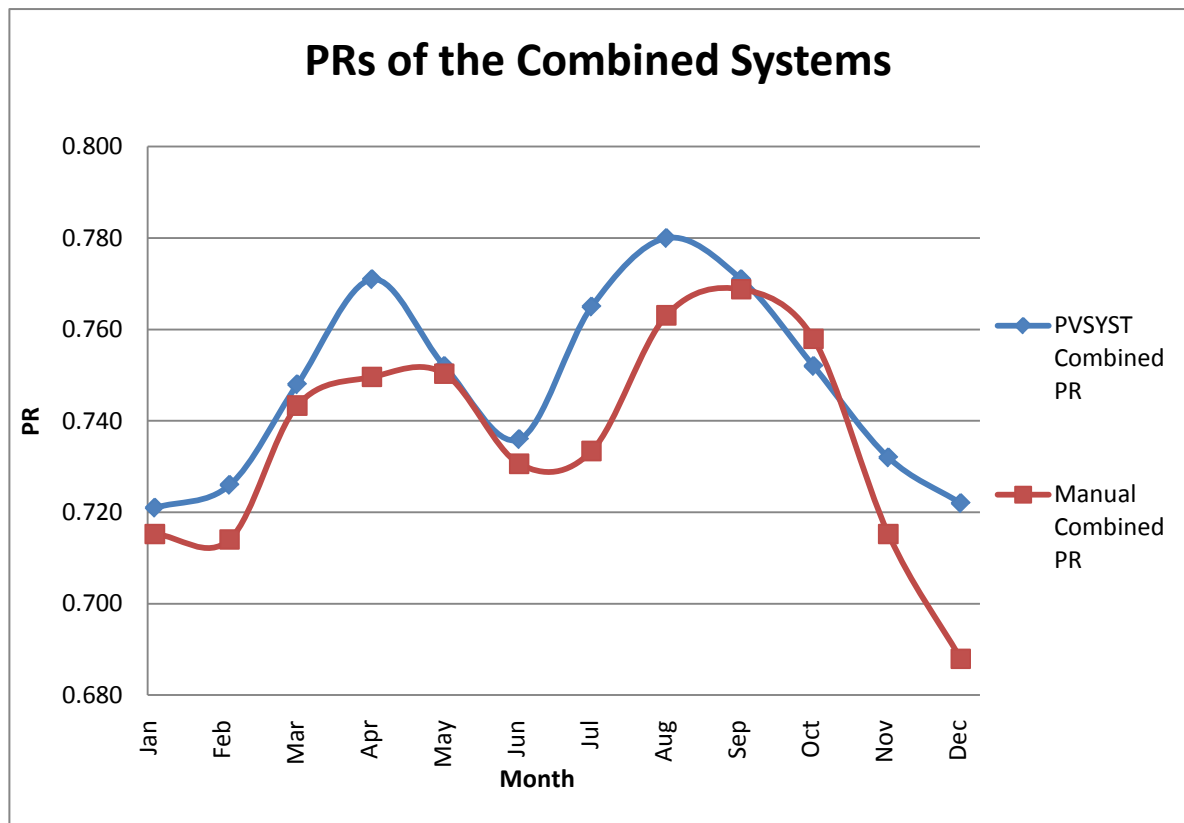


Figure 11: Performance Ratio (PR) results for both the manual and simulated estimate

The lower performances in the manual PR for April, July and December are a consequence of using the Solar Pathfinder data in position one (Figure 5). This data was affected by shading from the lift well and building to a greater extent, as the image was taken 40cm above the roof plane as opposed to the array height of approximately 3 metres.

7.2 Cable with the Banana Plug Adaptors

The cables used during experiments would most likely be banana plugs. As the voltages on these plugs could be in a range of up to 436V DC then the plugs would need additional insulation over the plastic of the connector and the first 30 mm of the cable. This would add an extra safety in case the cable starts to come away from the plug to expose live conductors.

7.3 ITO Submissions

The learning received from this approach is that a follow up call could be made soon (a couple of working day to a week) after the document(s) was sent to determine completeness and understanding of what was being asked, and to determine if they intend to submit a response. If anything this would be a courtesy contact to invite the companies to ask questions relating to the ITO and reiterate a point of contact for the University.

The consequence of making the call two days before the deadline in this project was that one of the companies declined to submit a tender. Unfortunately, this did not allow enough time to send out another ITO to be returned for the same deadline.

Another factor in not sending out a second round of invitations, extending the response period and issuing a more invitations, was that the project had a time constraint to be finished by December 2011. At the time, when the University was made aware of the failure to submit a response, there was still an expectation that the project would be completed by this deadline. On reflection, if a decision was made to go past the deadline then a second round of invitations would have been sent out.

7.4 Detailed Design Prior to Installation

The ITO failed to request a detailed design prior to installation. It would be a strong recommendation to include this in future ITOs. This would address the following issues:

- Performance estimation could be calculated prior to the installation. For this project it was difficult to estimate the performance of the system without a detailed design.
- Relevant authorities could be checked prior to installation, e.g. Australian Standards and Building Codes of Australia.
- Financial constraints – for this project funds had to be approved prior to 23rd December 2011 (university's last working day for the calendar year). Fortunately

the work started prior to this date and changes in the system were mostly worked out prior to the deadline.

- Clarification and changes – there were still two aspects of the system which were not investigated fully prior to work being carried out; patch panels (or test points) and battery configuration. A design sketch was received just before the financial deadline for the patch panels and the battery cable configuration was yet to be provided. This lack of specific design prior to the financial deadline meant that any changes to these systems would need to be covered by the initial fund allocations or be restricted to the minimum requirements necessary to cover what the contractors perceive as the system requirements.

7.5 Importance of Team Meeting Minutes

Throughout this project, meeting minutes were taken when formal meetings were held. The importance of this became more evident as the project developed with aspects of decisions made not being followed through. This reinforced a necessity for accurate and completeness of meeting minutes, which should detail:

- Those in attendance, including contact details.
- Date and time.
- Points discussed.
- Decisions made.
- Whose responsibility it was to carry out the decisions made.
- Date to be completed/ provided.
- Copies of all information presented must be provided to all attendees, and not just rely on emails being sent soon after adjournment.

It was not initially understood how integral this was to the project. Most in attendance seemed to take their own notes rather, which may not reflect on all the decisions made in the meeting.

7.6 Communication

In addition to meeting minutes, more communications would have been preferred in email form. This proved more difficult later in the project, as due to the lack of early designs, the system was being developed at such a fast pace that phone conversation and informal (1 on

1) meetings were the preferred type of communication. For the most part this worked well with the exception that all stakeholders needed to be informed of the decisions made and 'kept in the loop'.

7.7 Expected Battery Life

It is worth noting that the expected battery life may be reduced, depending on its use during higher temperatures (in daylight hours). If it was found that the inside of the enclosure was far exceeding ambient temperature, changing the ventilation method from natural to mechanical could partially compensate for this. In addition, the air intake for the batteries could be ducted from the inside of the building to the bottom of the enclosure. However, this was deemed to be unnecessary until data becomes available on the temperature of the inside of the battery enclosure.

A shed should provide the best protection for temperature increases from direct sunlight through a second layer of zinc on the roof and north-facing side (Figure 2). The zinc layer was spaced away from the shed wall, door, and roof for sufficient airflow between the layers.

7.8 University Safety Precautions and Procedures

It is highly recommended that staff and students participating in any type of experiments with the PV system should understand the system configuration and have knowledge of the safety features and their limitations prior to carrying out any experiments.

Any experiments carried out on the array must be carried out with 2 or more people in attendance, including a supervisor. Any one person must not be left alone with the patch panels unlocked.

Staff, student, guests or people performing maintenance on the array modules must adhere to the signage and safety procedures. Maximum weight limits do apply on the array structure, which include installing new equipment.

First aid kits, including defibrillator and oxygen can be found in the E&E building, level 2 staff room. For this reason no experiments are to be carried out unless the supervisor has security access to the staff room whilst the experiments are taking place.

7.9 Learning Experiences

It has been a great privilege to work on this project on behalf of the University in knowing how important this project is to the School of Engineering.

This project has been very insightful into the process of project management and experiencing firsthand the structure of an engineering project; from inviting tenders and selecting the most appropriate tender to leading meetings and negotiating changes in the systems' requirements.

At the start I did not appreciate how much work is involved prior to developing an ITO. In my experience I would now make sure the ground work is detailed and completed prior to starting an invitation. Additionally, I now have a broader understanding of what should be included in an ITO.

It has been a useful experience working with contractors for the first time in this industry. It has shown me what they consider in tender invitations and how they interpret their requirements. It was also interesting to see how they overcame problems in developing the installation and where they offer solutions that best suited their customer.

In developing the testing equipment recommendations in this report it was interesting when the project was involved with different areas of engineering that I had limited experience in. In understanding the signals to come from the equipment was not as straightforward as I anticipated and there were many subtle points that required further investigation. The data loggers required an understanding of how they measure signals in order to record data at a right sampling rate. This project has given much greater confidence in incorporating this type of equipment in my future engineering career.

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Appendix A

The Specifications from the Original Invitation To Offer [2]

Appendix B

Estimation of Weight on the Frame

Table 3: The estimated weight from the PV systems on the frame [11, 65-67].

	Specifications				Total		
	Quantity	Length (mm)	Width (mm)	Weight (kg)	Surface Area (mm ²)	Surface Area (m ²)	Weight (kg)
SunPower E19	9	1559	798	15.0	11196738	11.2	135.0
Amplusun a-Si 100W	15	1414	1114	21.0	23627940	23.6	315.0
Solar Frontier SF140	24	1257	977	12.4	29474136	29.5	297.6
HHV Solar 250W	8	1668	997	24.0	13303968	13.3	192.0
Q.Cells 95W	21	1196	636	14.5	15973776	16.0	304.5
(At most) Estimate for cabling, J/B, cable tray, etc.		+25%		On 15/09/2011	Total	77.6	1174.5
(At most) Estimate for cabling, J/B, cable tray, etc.		+25%		Final design	Total	64.1	1181.4

Detailed Calculation are Attached in an Excel Workbook

Appendix D

Assets Currently Owned by the University - Battery Enclosures (Photo)



Figure 13: Battery enclosure too large to be transported to the roof of the E&E Building

Appendix E

Battery Enclosure Illustrations

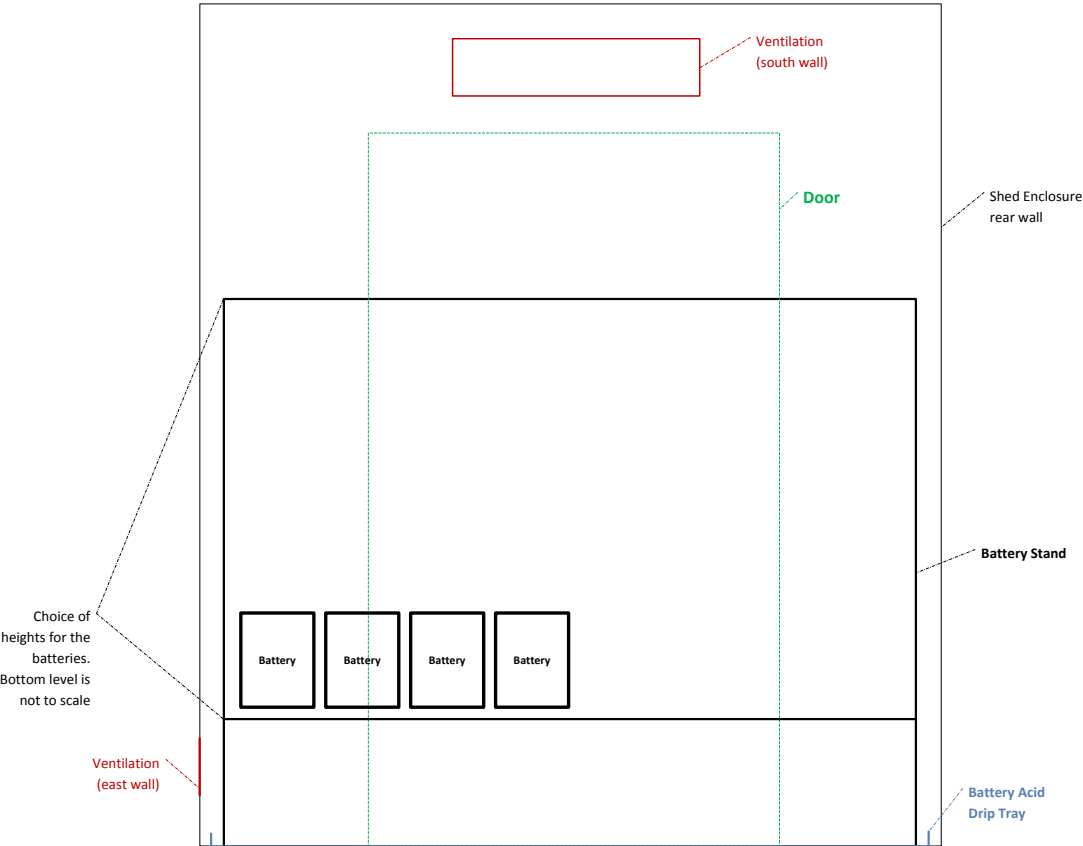


Figure 14: Illustration of the battery enclosure from the north side

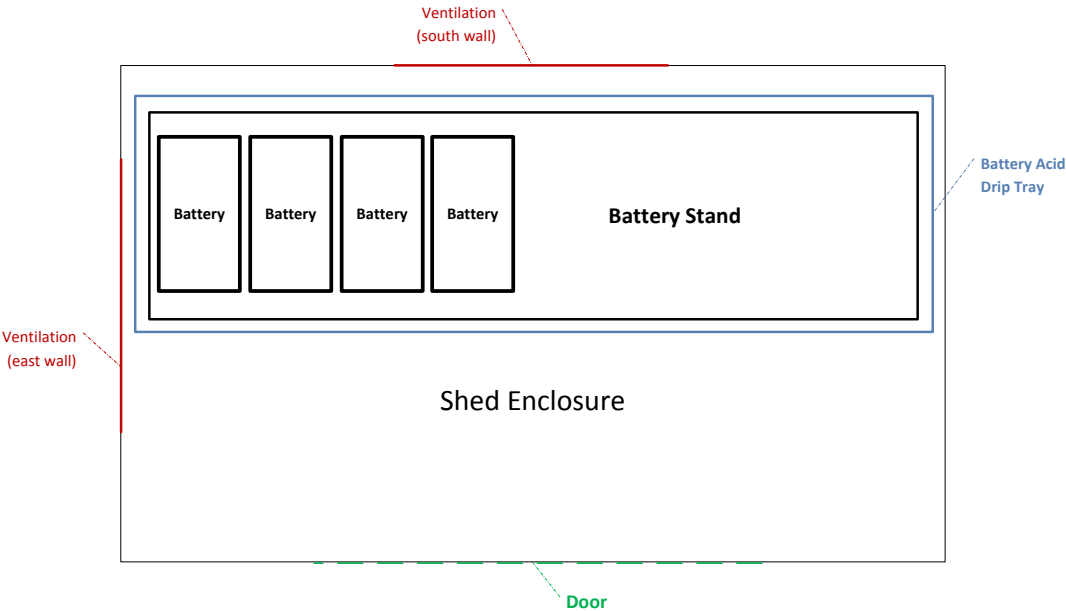


Figure 15: A sketch of the battery enclosure from a top down view.

Appendix F

Battery Ventilation

As per AS4086.2: *Secondary batteries for use with stand-alone power systems* [23].

Exhaust ventilation rate - The minimum exhaust ventilation rate required to maintain hydrogen concentration below 2% is calculated by the following equation:

$$q_v = 0.006 \times n \times I$$

Where

q_v = the minimum exhaust ventilation rate, in litres per second

n = the number of battery cells

I = the charging rate, in amperes

If there is more than one battery in an enclosure, then the total exhaust ventilation rate is the sum of the rate of all the batteries.

Natural ventilation - If natural ventilation is used, the minimum size of inlet and outlet apertures is determined from the following equation:

$$A = 100q_v$$

Where

A = the minimum area of the apertures, in square centimetres

q_v = the minimum exhaust ventilation rate, in litres per second

This determined the calculated to be:

$$A = \frac{0.006 \times 4 \times 0.5 \times 100}{0.02} = 60\text{cm}^2$$

The dimensions of the ventilation (internal area) purchased were:

$$A = 13.5 \times 58.0 = 783\text{cm}^2$$

Appendix G

Line Diagrams for Array and Islanding Systems

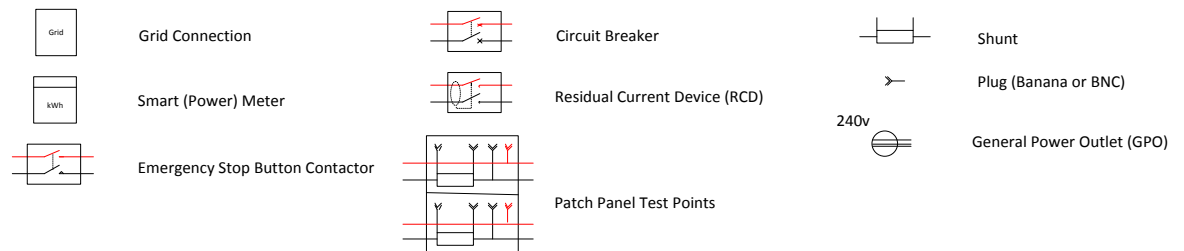


Figure 16: Key for the system line diagrams

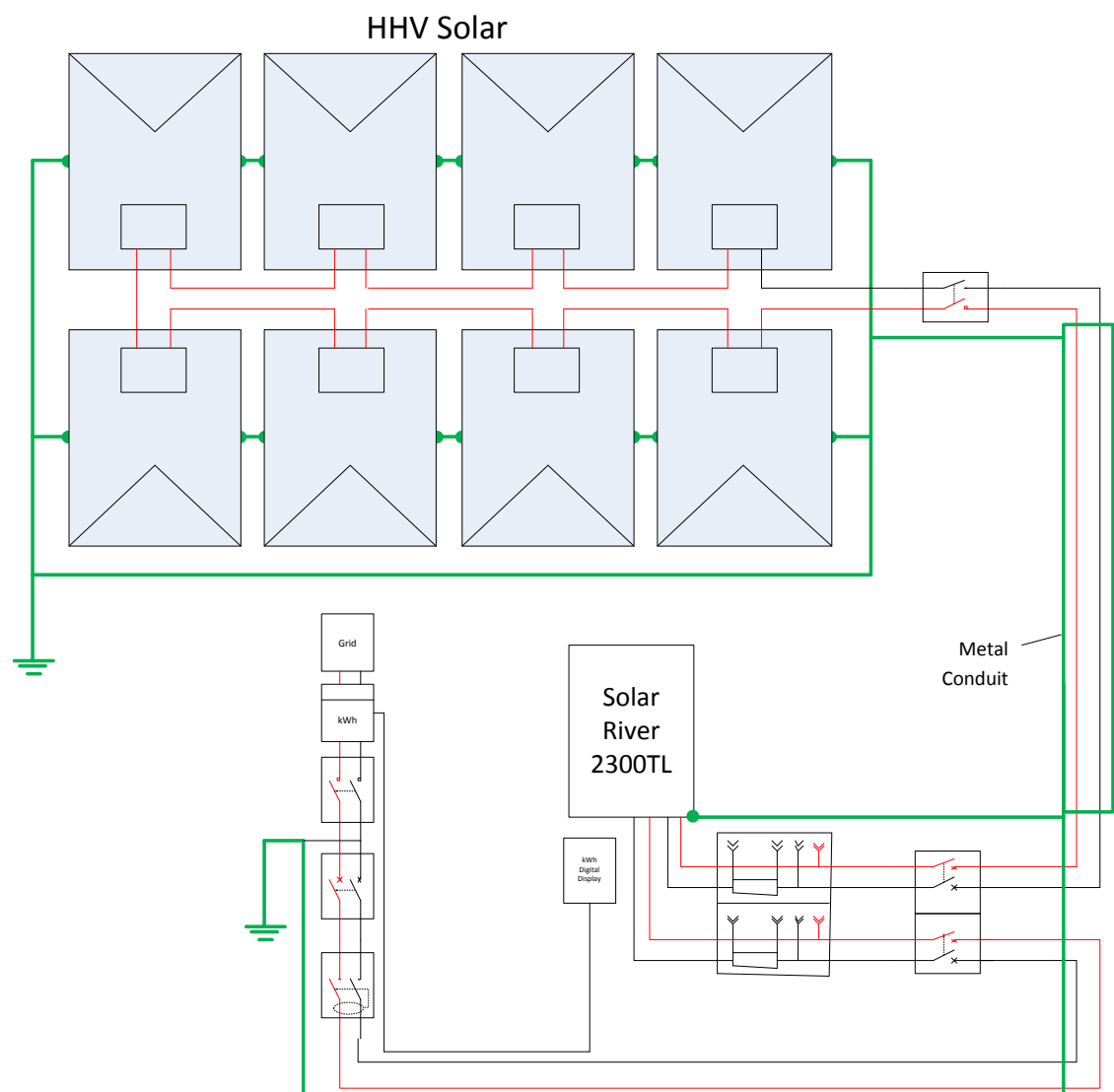


Figure 17: Line diagram of the proposed HVV Solar and Solar River system.

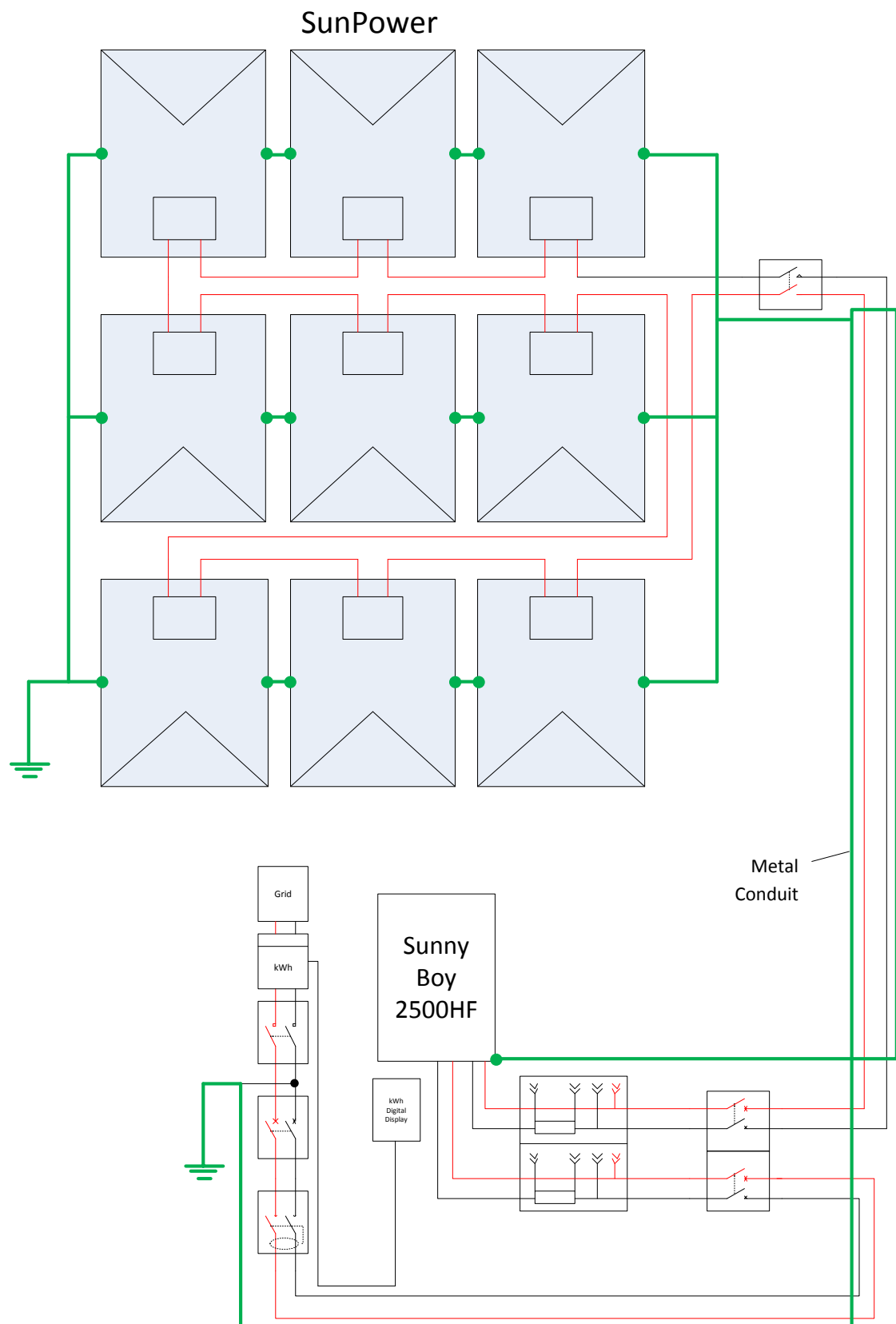


Figure 18: Line diagram of the proposed SunPower and SMA SB2500HF system.

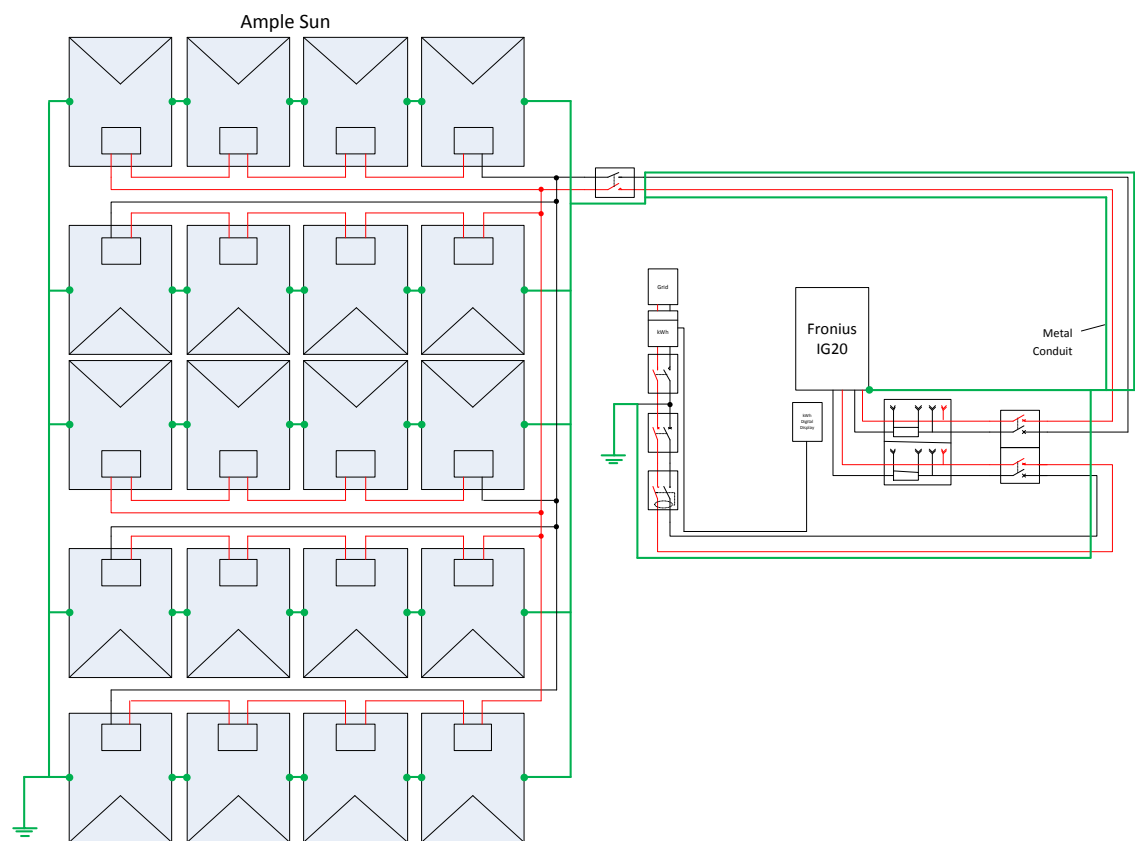


Figure 19: Line diagram of the proposed Ample Sun and Fronius system.

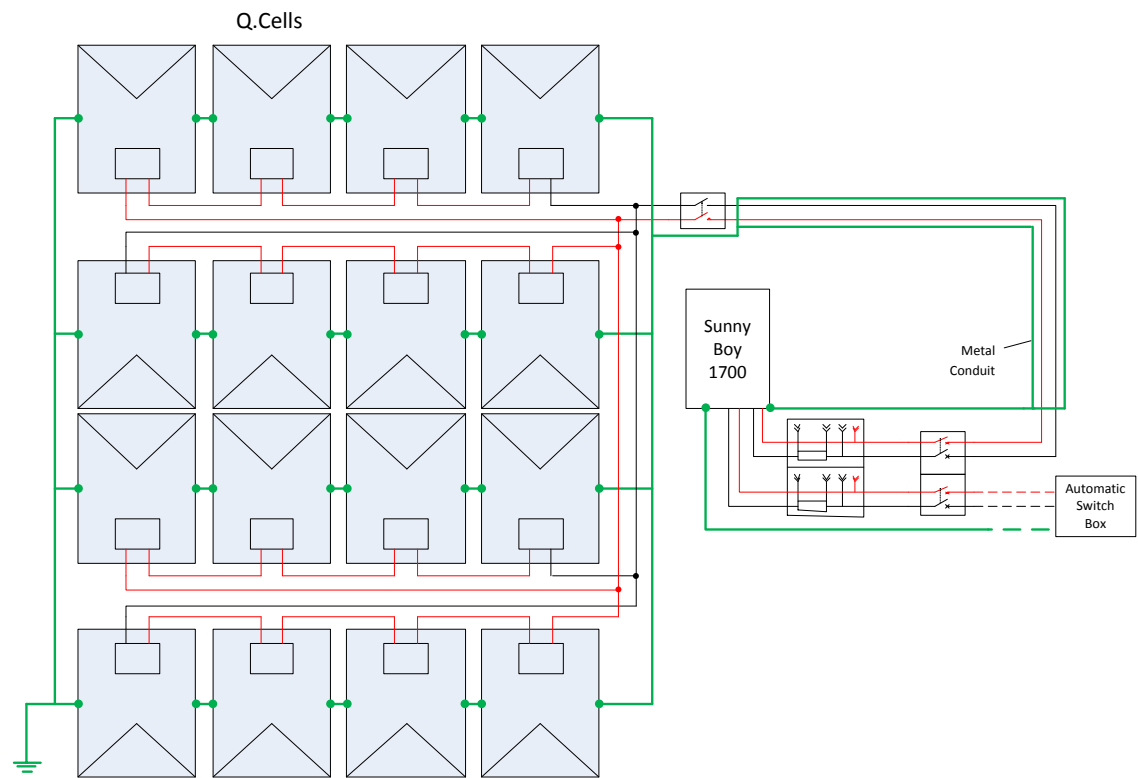


Figure 20: Line diagram of the proposed Q.Cells and SMA SB1700 system.

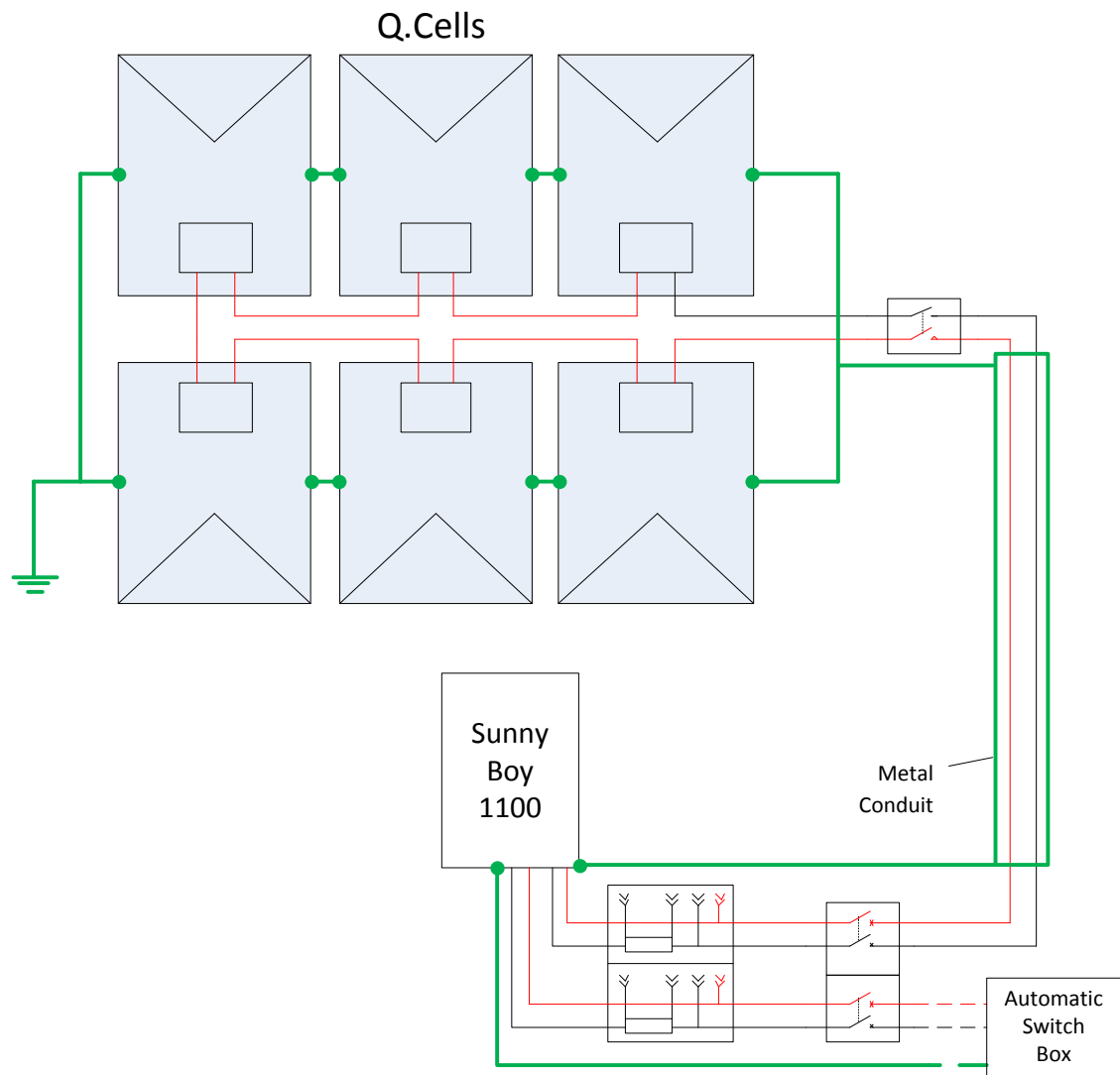


Figure 21: Line diagram of the proposed Q.Cells and SMA SB1100 system.

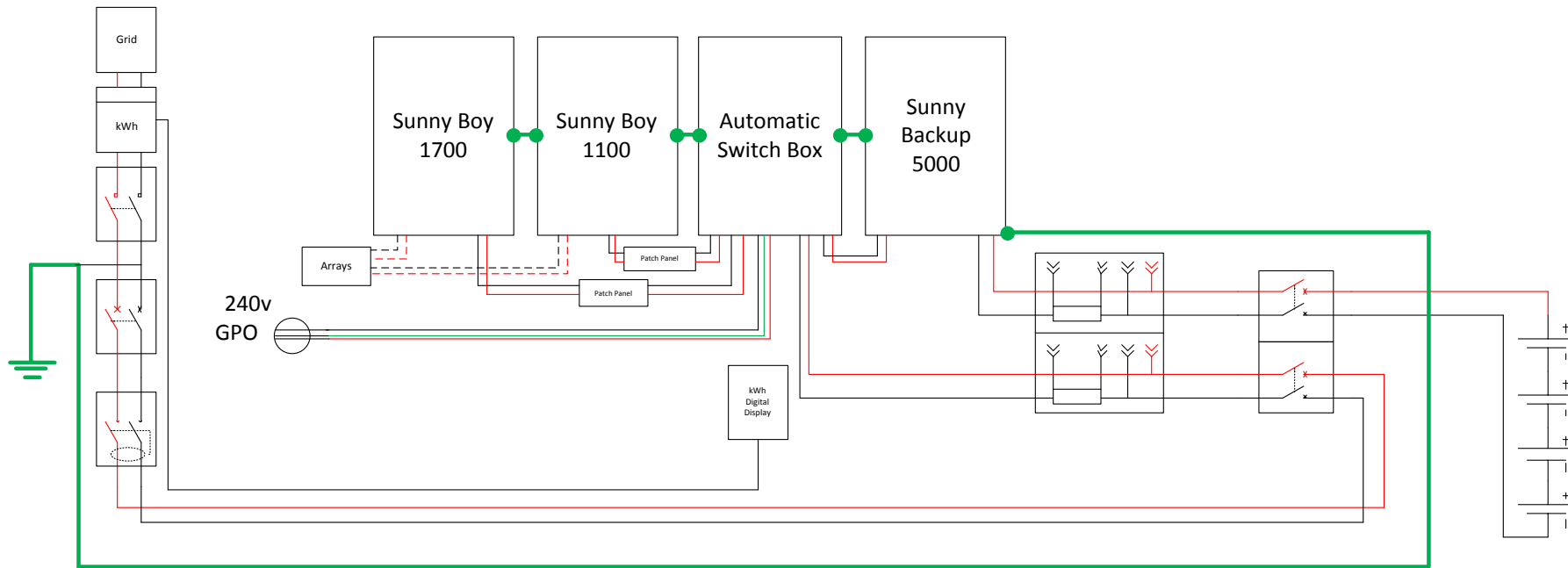


Figure 22: Line diagram of the proposed islanding system.

Further details can be found in an attached Excel workbook.

Appendix H

The Updated and Corrected Invitation To Tender

Appendix I

Quotes Received for Purchasing and Installing the Monitoring Equipment.

Table 4: Details of the quotes received for the monitoring equipment [79-82].

Parameter	Component	Manufacturer	Model	Quantity	Unit Price	Cost	GST
Data Recorder	Data Logger	Datataker	DT800 + power supply	1	\$6,680.00	\$6,680.00	AUS (ex. GST)
		NI	CRIO-9076	1	\$5,132.50	\$5,132.50	AUS (ex. GST)
Temperature	Ambient	Envirodata	SS11 Sensor Shelter	1	\$435.00	\$435.00	AUS (ex. GST)
		Envirodata	Freight not accurate (\$25.00 for 1 sensor)	1	\$25.00	\$25.00	AUS (ex. GST)
	Module	Hinco	IP100	20	\$98.00	\$1,960.00	AUS (ex. GST)
Wind	Vane	NRG	#200P	1	\$215.00	\$215.00	USD
	Anemometer	NRG	#40C + MEASNET (individually calibrated)	2	\$395.00	\$790.00	USD
			NRG Freight	1	\$39.00	\$39.00	USD
Solar Irradiance	Pyranometer	Middleton	EQ08 (30m cable) + calibration	1	\$2,387.00	\$2,387.00	AUS (ex. GST)
		Kipp&Zonen	CM4 with 15m cable	1	\$2,260.00	\$2,260.00	AUS
Enclosure	Junction Box	Clipsal	265/7 GY	1	\$180.89	\$180.89	AUS (ex. GST)
Network Connection	Murdoch University	Murdoch University	See email	1	\$475.00	\$475.00	AUS (ex. GST)
Electrical contractor	Twin GPO	Nilsen	See email	1	\$650.00	\$650.00	AUS (ex. GST)
Fixing of the monitoring equipment will be done by the Technical Officer as this is an educational resource, no extra cost.							

Items with higher quantities indicate where items are replaced instead of recalibrated.

The prices in Table 4 were given during October and November 2011 and had a 30 day limit. These prices should be taken as an estimate only and at the time of purchasing new quotes should be sought.

Both the dataTaker and National Instruments data loggers have been included, but only one would need to be purchased.

Appendix J

Manual Performance Estimate [20]

Temperature Derating Factor

Q.Cells Q.Smart 90	– Temperature derating (%/ K)	– 0.38 ± 0.04
SunPower SPR-238E-WHT-D	– Temperature derating (%/ K)	– 0.38
AmpleSun ASF100	– Temperature derating (%/ °C)	– 0.20
HHV Solar HSDTDF24255P	– Temperature derating (%/ °C)	– 0.46

The temperature derating at 30°C above ambient temperature was calculated by the following formula [AS4509.2 xxxxxxxx]:

$$f_{temp} = 1 + [\gamma \times (T_{cell_eff} - T_{STC})]$$

Where

f_{temp} = temperature de-rating factor, dimensionless.

γ = power temperature co-efficient per °C.

T_{cell_eff} = average daily cell temperature, in °C.

T_{STC} = cell temperature at Standard Test Conditions, in °C.

The cell temperature (T_{cell_eff}) can be determined by:

$$T_{cell_eff} = T_{ave_amb} + 25^{\circ}\text{C}$$

Where

T_{cell_eff} = average daily cell temperature, in °C.

T_{ave_amb} = the daily ambient temperature, in °C.

The specific yield can be determined by:

$$Y_f = \frac{P_{array,STC} \times f_{temp} \times f_{manu} \times f_{dirt} \times H_{tilt} \times \eta_{PV_inv} \times \eta_{inv} \times \eta_{inv_SW}}{P_{array,STC}}$$

Where

$P_{\text{array,STC}}$	- rated output power of the module under standard test conditions, in watts.
f_{temp}	- temperature derating factor, dimensionless.
f_{man}	- derating factor for manufacturing tolerance, dimensionless.
f_{dirt}	- derating factor for dirt/soiling, dimensionless.
H_{tilt}	- daily irradiation on the tilted plane, in PSH.
$\eta_{\text{PV_inv}}$	- efficiency of the (DC) cables and connections from the array to the inverter, dimensionless.
η_{inv}	- efficiency of the inverter used, dimensionless.
$\eta_{\text{PV_inv}}$	- efficiency of the (AC) cables and connections from the inverter to the switchboard, dimensionless.

Detailed Calculation are Attached in an Excel Workbook

Appendix K

Shade modelling

Manual shade modelling has been estimated from the photographs provided and with the positions illustrated in Figure 5.

Table 5: An estimated summary of the direct beam irradiance from the Solar Pathfinder photos.

Month	Shading Position					
	1	2	3	4	5	6
January	0.810	0.985	0.975	1.000	0.934	0.985
February	0.915	1	1	1.000	0.960	0.940
March	0.940	0.993	0.995	1.000	0.965	0.985
April	0.900	0.82	0.87	0.950	0.998	0.985
May	0.850	0.63	0.5	0.460	0.998	0.985
June	0.730	0.49	0.23	0.462	0.998	0.970
July	0.730	0.52	0.4	0.465	0.998	0.970
August	0.900	0.69	0.78	0.860	0.998	0.975
September	0.930	0.992	0.995	1.000	0.995	0.985
October	0.940	1	1	1.000	0.962	0.980
November	0.835	0.984	0.974	1.000	0.934	0.950
December	0.770	0.96	0.97	0.992	0.920	0.930

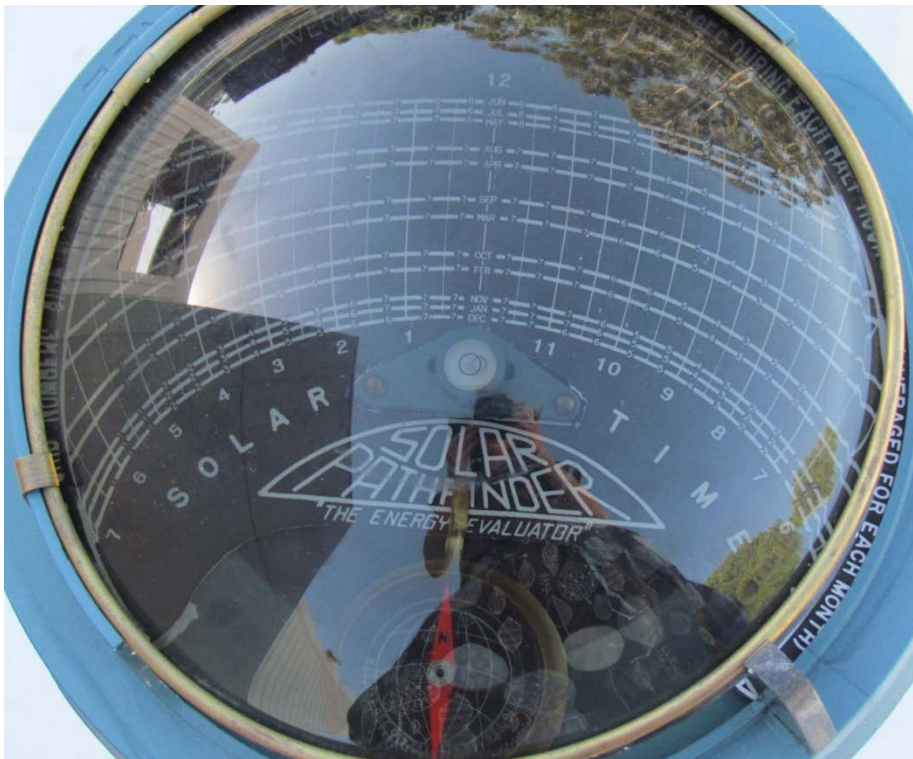
Solar Pathfinder Photos

Figure 23: Solar Pathfinder photo from position 1 [60].

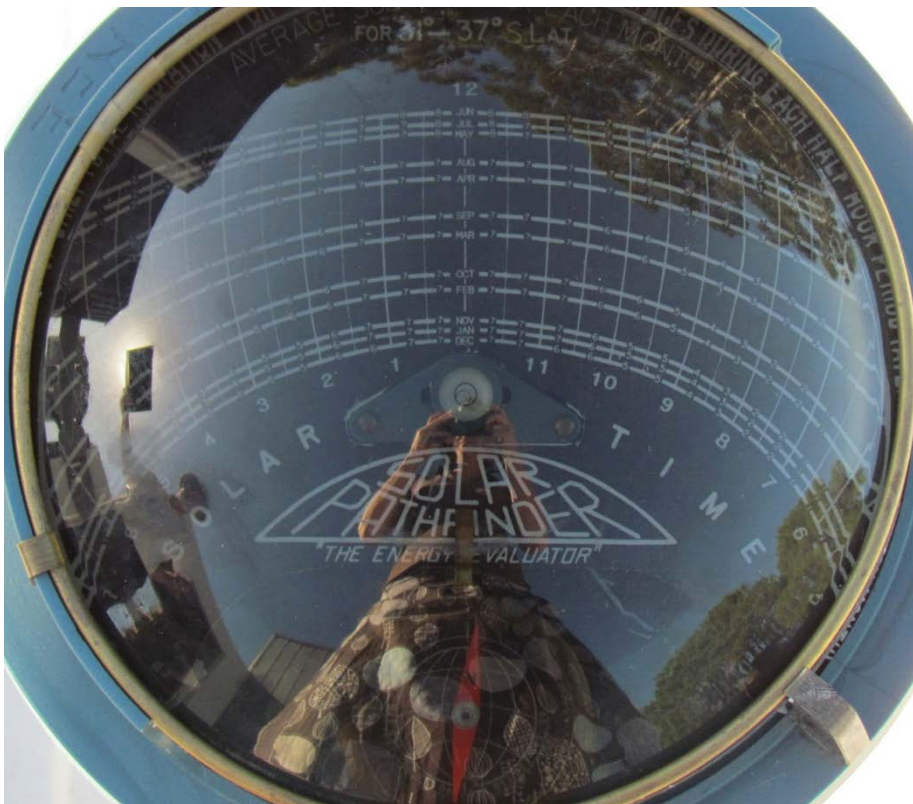


Figure 24: Solar Pathfinder photo from position 2 [60].

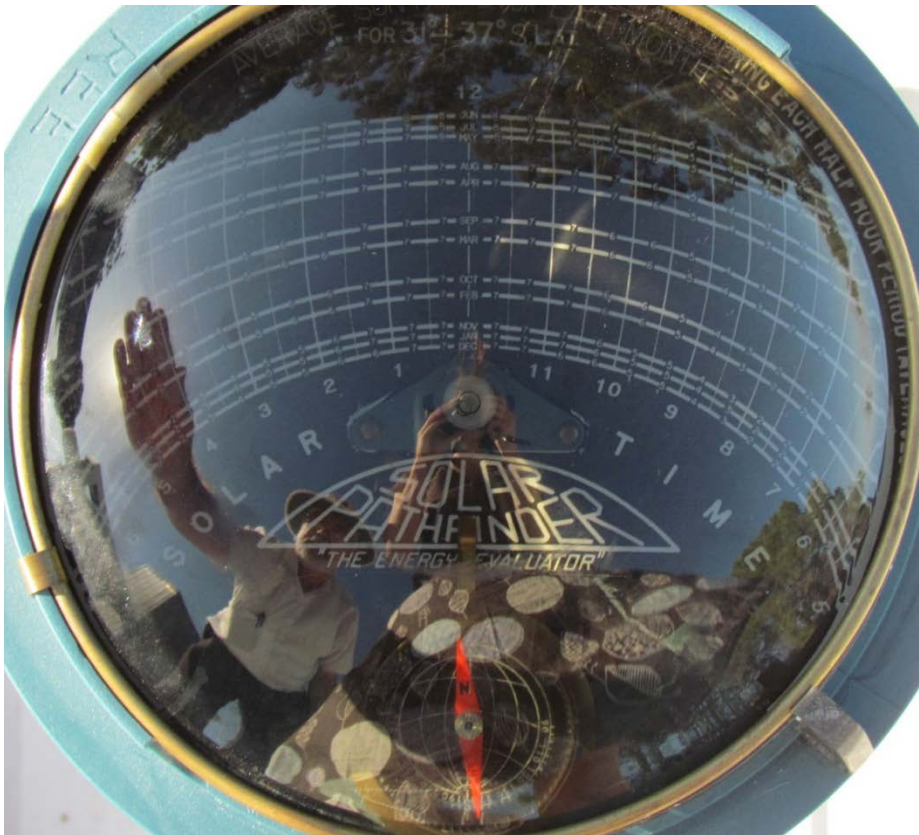


Figure 25: Solar Pathfinder photo from position 3 [60].



Figure 26: Solar Pathfinder photo from position 4 [60].



Figure 27: Solar Pathfinder photo from position 5 [60].



Figure 28: Solar Pathfinder photo from position 6 [60].

Appendix L

PVsyst Simulation

Geographical site parameters

Geographical Coordinates | Monthly meteo

Location

Site name: Murdoch

Country: Australia | Region: Australia

Latitude: -32.06 (Decimal) or -32° 4' (Deg. min.) (+ = North, - = South hemisph.)

Longitude: 115.80 (Decimal) or 115° 48' (Deg. min.) (+ = East, - = West of Greenwich)

Altitude: 19 M above sea level

Time zone: 8 Corresponding to an average difference

Legal Time - Solar Time = 0h 17m

Project location

You may re-define here the site name (your project's location), and eventually the geographical coordinates.

For defining new monthly meteo values, please define a new site in the database using "Tools"/"Geographic Location", or import them with "Tools" "Import meteo data".

Sun paths

Print

Cancel OK

Geographical site parameters

Geographical Coordinates: Monthly meteo

Site: **Murdoch (Australia)**

Data source: Meteonorm

	Global Irrad. kWh/m ² .mth	Diffuse kWh/m ² .mth	Temper. °C	Wind Vel. m/s
January	241.8	75.5	24.5	4.10
February	190.8	63.9	24.3	4.49
March	186.0	59.3	22.9	3.90
April	120.0	49.0	19.1	3.00
May	99.5	39.2	16.1	2.80
June	81.0	33.0	13.7	2.70
July	84.6	36.2	13.2	2.99
August	118.7	43.7	13.3	2.70
September	149.7	54.3	14.2	3.10
October	191.0	67.8	16.1	3.60
November	224.7	71.3	19.2	3.80
December	248.9	76.5	21.7	4.20
Year	1936.7	669.7	18.2	3.4

Required Data

☒ Horizontal global irradiation

☒ Average Ext. Temperature

Extra data

☒ Horizontal diffuse irradiation

☒ Wind velocity

Irradiation units

☐ kWh/m².day

☒ kWh/m².mth

☐ MJ/m².day

☐ MJ/m².mth

☐ W/m²

☐ Clearness Index Kt

Cancel

OK

Orientation, Variant "New simulation variant"

Field type: Fixed Tilted Plane

Field Parameters

Plane Tilt: 32°

Azimuth: 0.0°

Yearly meteo yield

Transposition Factor FT: 1.09

Loss By Respect To Optimum: -0.3%

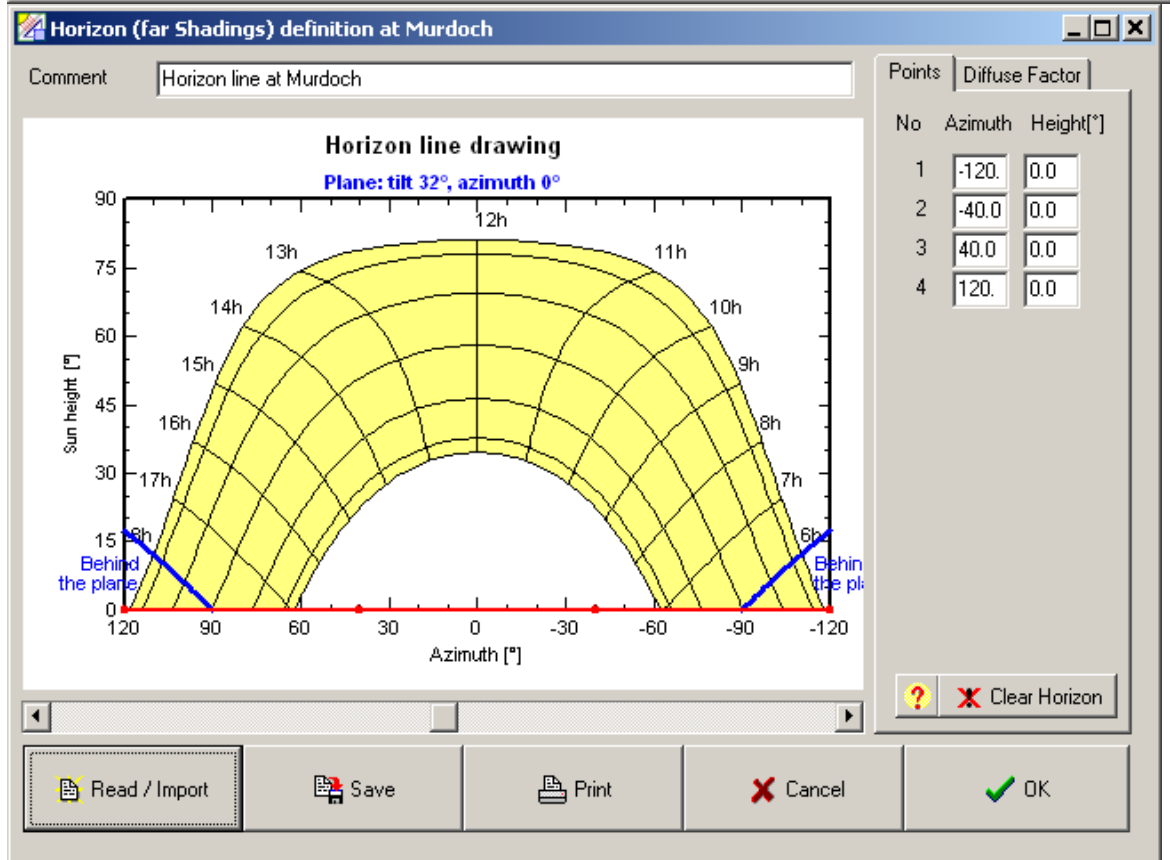
Global on collector plane: 2113 kWh/m²

Optimisation by respect to:

- ☒ Yearly irradiation yield
- ☐ Summer (Oct-Mar)
- ☐ Winter (Apr-Sept)

Show Optimisation

Cancel OK

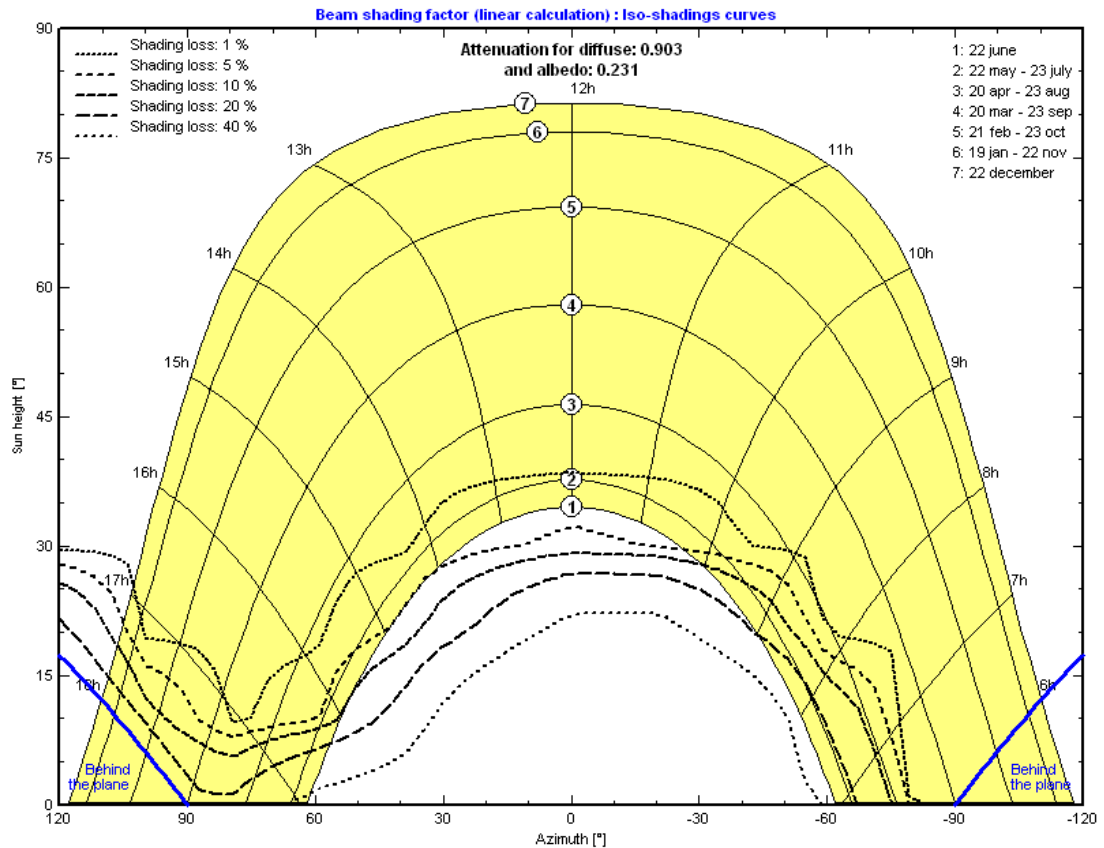


Shading factor table (linear), for the beam component

Azimuth	-180°	-160°	-140°	-120°	-100°	-80°	-60°	-40°	-20°	0°	20°	40°	60°	80°	100°	120°	140°	160°	180°
Height																			
90°	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
80°	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
70°	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
60°	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
50°	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
40°	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.975	1.000
30°	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.990	0.954	0.935	0.962	0.996	1.000	1.000	1.000	1.000	0.837	0.949	1.000
20°	Behind	Behind	1.000	1.000	1.000	1.000	0.768	0.495	0.509	0.760	0.940	1.000	1.000	1.000	0.764	0.674	Behind	Behind	Behind
10°	Behind	Behind	Behind	1.000	1.000	1.000	0.822	0.335	0.070	0.000	0.339	0.746	0.959	1.000	0.869	0.528	Behind	Behind	Behind
2°	Behind	Behind	Behind	Behind	1.000	1.000	0.693	0.188	0.000	0.000	0.278	0.425	0.524	0.783	0.738	Behind	Behind	Behind	Behind

Shading factor for diffuse: 0.903 and for albedo: 0.231

Murdoch University Grid Connected: Murdoch Shading Scene



Project's parameter: Albedo for the project's situation

Albedo values ?

Monthly values

Jan.	0.14	July	0.14
Feb.	0.14	Aug.	0.14
Mar.	0.14	Sep.	0.14
Apr.	0.14	Oct.	0.14
May	0.14	Nov.	0.14
June	0.14	Dec.	0.14

Set a common value

Common value

(Default: albedo = 0.2)

Usual values for albedo

Urban situation	0.14 - 0.22
Grass	0.15 - 0.25
Fresh Grass	0.26
Fresh snow	0.82
Wet snow	0.55 - 0.75
Dry asphalt	0.09 - 0.15
Wet asphalt	0.18
Concrete	0.25 - 0.35
Red tiles	0.33
Aluminium	0.85
New galvanised steel	0.35
Very dirty galvanised steel	0.08

Site-dependent Design parameters

Reference temperatures for array design by respect to the inverter input voltages ?

Lower temperature for VmaxAbs limit °C ☐ Default

Winter operating temperature for VmppMax design °C ☒

Usual operating temperature under 1000 W/m °C ☒

Summer operating temperature for VmppMin design °C ☒

Hourly Simulation Progress

Status: Simulation ended successfully

Attenuation factors for Diffuse

	IAM	Shading	IAM*Shading
Diffuse	0.962	0.903	0.868
Albedo	0.822	0.231	0.174

Display:

☐ Hourly Values

☒ Daily Values

☐ Monthly Values

Display daily values

Simulation 31/12/90

Meteo: Global, Diffuse, Tamb 8.63, 1.93kWh/m².day, 19.1°C, 0.0 m/s

On coll: Global, Diffuse, Glob. eff. 7.34, 1.66, 0.09, 6.87 kWh/m².day

System: EMax, ENet, EUse 46.3, 46.1, 43.50kWh/day

Load: ELoad, EUsed, EOver Unlimited, 0.0, 0.0 kWh/day

PVSYST V5.5					01/02/12	Page 1/5
Grid-Connected System: Simulation parameters						
Project :		Murdoch University Grid Connected				
Geographical Site		Murdoch		Country	Australia	
Situation		Latitude	32.1°S	Longitude	115.8°E	
Time defined as		Legal Time	Time zone UT+8	Altitude	19 m	
		Albedo	0.14			
Meteo data :		Murdoch University from NASA-SSE, Synthetic Hourly data				
Simulation variant :		001 E&E Array				
		Simulation date	01/02/12 11h10			
Simulation parameters						
Collector Plane Orientation		Tilt	32°	Azimuth	0°	
Horizon		Free Horizon				
Near Shadings		Linear shadings				
PV Arrays Characteristics (5 kinds of array defined)						
Array#1 : PV module		Si-mono	Model	SPR-238E-WHT-D		
		Manufacturer	SunPower			
Number of PV modules		In series	9 modules	In parallel	1 strings	
Total number of PV modules		Nb. modules	9	Unit Nom. Power	238 Wp	
Array global power		Nominal (STC)	2.14 kWp	At operating cond.	1.93 kWp (50°C)	
Array operating characteristics (50°C)		U mpp	326 V	I mpp		
Array#2 : PV module		Si-poly	Model	HSTDF24255P		
		Manufacturer	HHV			
Number of PV modules		In series	8 modules	In parallel	1 strings	
Total number of PV modules		Nb. modules	8	Unit Nom. Power	250 Wp	
Array global power		Nominal (STC)	2.00 kWp	At operating cond.	1.81 kWp (50°C)	
Array operating characteristics (50°C)		U mpp	259 V	I mpp		
Array#3 : PV module		CIS	Model	ASF100		
		Manufacturer	AmpleSun			
Number of PV modules		In series	4 modules	In parallel	5 strings	
Total number of PV modules		Nb. modules	20	Unit Nom. Power	100 Wp	
Array global power		Nominal (STC)	2.00 kWp	At operating cond.	1.82 kWp (50°C)	
Array operating characteristics (50°C)		U mpp	257 V	I mpp		
Array#4 : PV module		CIS	Model	Q.SMART 90 E&E		
		Manufacturer	Q-Cells SE			
Number of PV modules		In series	3 modules	In parallel	2 strings	
Total number of PV modules		Nb. modules	6	Unit Nom. Power	90 Wp	
Array global power		Nominal (STC)	540 Wp	At operating cond.	481 Wp (50°C)	
Array operating characteristics (50°C)		U mpp	161 V	I mpp		
Array#5 : PV module		CIS	Model	Q.SMART 90 E&E		
		Manufacturer	Q-Cells SE			
Number of PV modules		In series	4 modules	In parallel	4 strings	
Total number of PV modules		Nb. modules	16	Unit Nom. Power	90 Wp	
Array global power		Nominal (STC)	1.44 kWp	At operating cond.	1.28 kWp (50°C)	
Array operating characteristics (50°C)		U mpp	215 V	I mpp		
Total Arrays global power		Nominal (STC)	8 kWp	Total	59 modules	
		Module area	72.7 m²			

PVSYST V5.5		01/02/12	Page 2/5
Grid-Connected System: Simulation parameters (continued)			
Array#1 : Inverter	Model	Sunny Boy SB 2500HF-30	
	Manufacturer	SMA	
Characteristics	Operating Voltage	175-560 V	Unit Nom. Power 2.5 kW AC
Array#2 : Inverter	Model	SolarRiver_2300TL	
	Manufacturer	SamillPower	
Characteristics	Operating Voltage	200-500 V	Unit Nom. Power 2.0 kW AC
Array#3 : Inverter	Model	IG 20 (outdoor)	
	Manufacturer	Fronius	
Characteristics	Operating Voltage	150-400 V	Unit Nom. Power 1.8 kW AC
Array#4 : Inverter	Model	Sunny Boy SB 1100	
	Manufacturer	SMA	
Characteristics	Operating Voltage	139-320 V	Unit Nom. Power 1.0 kW AC
Array#5 : Inverter	Model	Sunny Boy SB 1700	
	Manufacturer	SMA	
Characteristics	Operating Voltage	139-320 V	Unit Nom. Power 1.6 kW AC
PV Array loss factors			
Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind) 0.0 W/m²K / m/s
=> Nominal Oper. Coll. Temp. (G=800 W/m², Tamb=20°C, Wind velocity = 1m/s.) NOCT 56 °C			
Wiring Ohmic Loss	Array#1	917 mOhm	Loss Fraction 1.5 % at STC
	Array#2	606 mOhm	Loss Fraction 1.5 % at STC
	Array#3	622 mOhm	Loss Fraction 1.5 % at STC
	Array#4	865 mOhm	Loss Fraction 1.5 % at STC
	Array#5	577 mOhm	Loss Fraction 1.5 % at STC
	Global		Loss Fraction 1.5 % at STC
Module Quality Loss	Array#1,	Loss Fraction	2.5 %
	Array#2,	Loss Fraction	1.5 %
	Array#3,	Loss Fraction	-1.3 %
	Array#4,	Loss Fraction	-1.5 %
	Array#5,	Loss Fraction	-1.5 %
Module Mismatch Losses	Array#1,	Loss Fraction	2.0 % at MPP
	Array#2,	Loss Fraction	2.0 % at MPP
	Array#3,	Loss Fraction	1.0 % at MPP
	Array#4,	Loss Fraction	1.0 % at MPP
	Array#5,	Loss Fraction	1.0 % at MPP
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Parameter 0.05
User's needs :	Unlimited load (grid)		

